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Kamoi et al.

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(45) Date of Patent: Oct. 20, 2015

(54) **LIGHTING DEVICE AND LUMINAIRE**

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(73) Assignee: **Panasonic Intellectual Property Management Co., Ltd.**, Osaka (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/444,017**

(22) Filed: **Jul. 28, 2014**

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(30) **Foreign Application Priority Data**

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Aug. 2, 2013 (JP) 2013-161831

(51) **Int. Cl.**
H05B 37/02 (2006.01)
H05B 33/08 (2006.01)

(52) **U.S. Cl.**
CPC ***H05B 33/0818*** (2013.01)

(58) **Field of Classification Search**
USPC .... 315/185 R, 186, 224–226, 291, 294, 315/297, 299, 300, 307, 308, 360
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,919,936 B2 4/2011 Liu et al.
8,148,919 B2 4/2012 Liu et al.
8,237,379 B2 8/2012 Liu
8,253,352 B2 8/2012 Liu
8,593,067 B2 11/2013 Iwai et al.
2008/0224625 A1* 9/2008 Greenfeld 315/201
2010/0026208 A1* 2/2010 Shteynberg et al. 315/297
2010/0033109 A1 2/2010 Liu et al.
2011/0181198 A1 7/2011 Iwai et al.
2011/0248648 A1 10/2011 Liu
2011/0254462 A1* 10/2011 Ruan et al. 315/291
2011/0316447 A1 12/2011 Liu
2012/0032613 A1 2/2012 Liu et al.
2012/0187847 A1* 7/2012 Hamamoto et al. 315/125
2012/0262087 A1 10/2012 Watanabe et al.
2014/0117865 A1* 5/2014 Deng et al. .... 315/200 R

FOREIGN PATENT DOCUMENTS

JP	2010-040509	2/2010
JP	2011-155101	8/2011
JP	2011-210659	10/2011
JP	2011-223800	11/2011
JP	2012-043657	3/2012
JP	2012-109141	6/2012

(Continued)

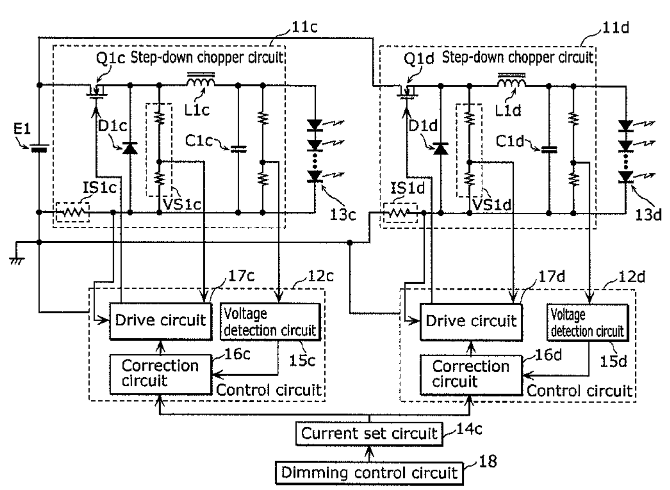
Primary Examiner — Tung X Le

(74) *Attorney, Agent, or Firm* — Renner, Otto, Boisselle & Sklar, LLP

(57) **ABSTRACT**

A lighting device includes a DC/DC converter (step-down chopper circuit) and a control circuit that includes a correction circuit. The correction circuit corrects the timing at which a switching element included in the DC/DC convertor is turned OFF based on a voltage value across a solid-state light-emitting element (LED unit). The correction is made such that an average value of a current flowing through an inductor included in the DC/DC converter is within a predetermined range regardless of a voltage value across the solid-state light-emitting element.

13 Claims, 22 Drawing Sheets



(56) **References Cited**

FOREIGN PATENT DOCUMENTS

JP	2012-175887	9/2012
JP	2012-221899	11/2012
JP	2012-222322	11/2012

* cited by examiner

FIG. 1
PRIOR ART

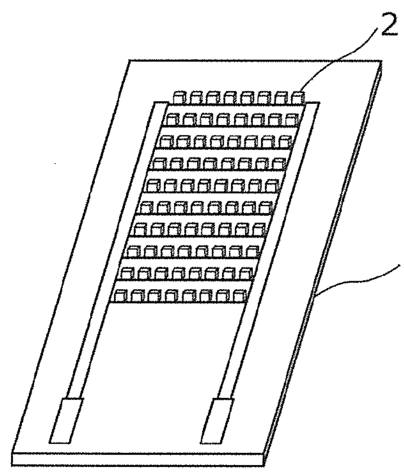


FIG. 2
PRIOR ART

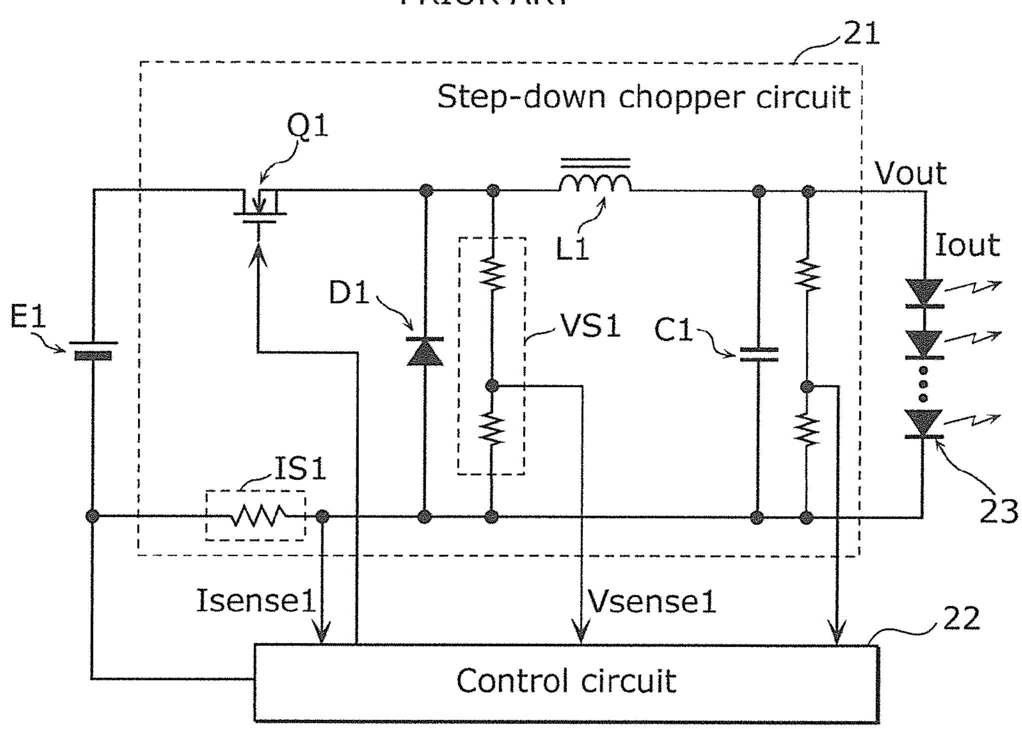


FIG. 3
PRIOR ART

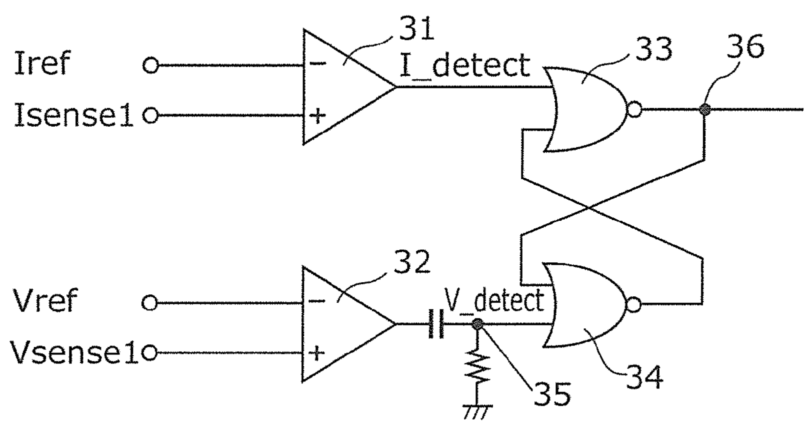


FIG. 4
PRIOR ART

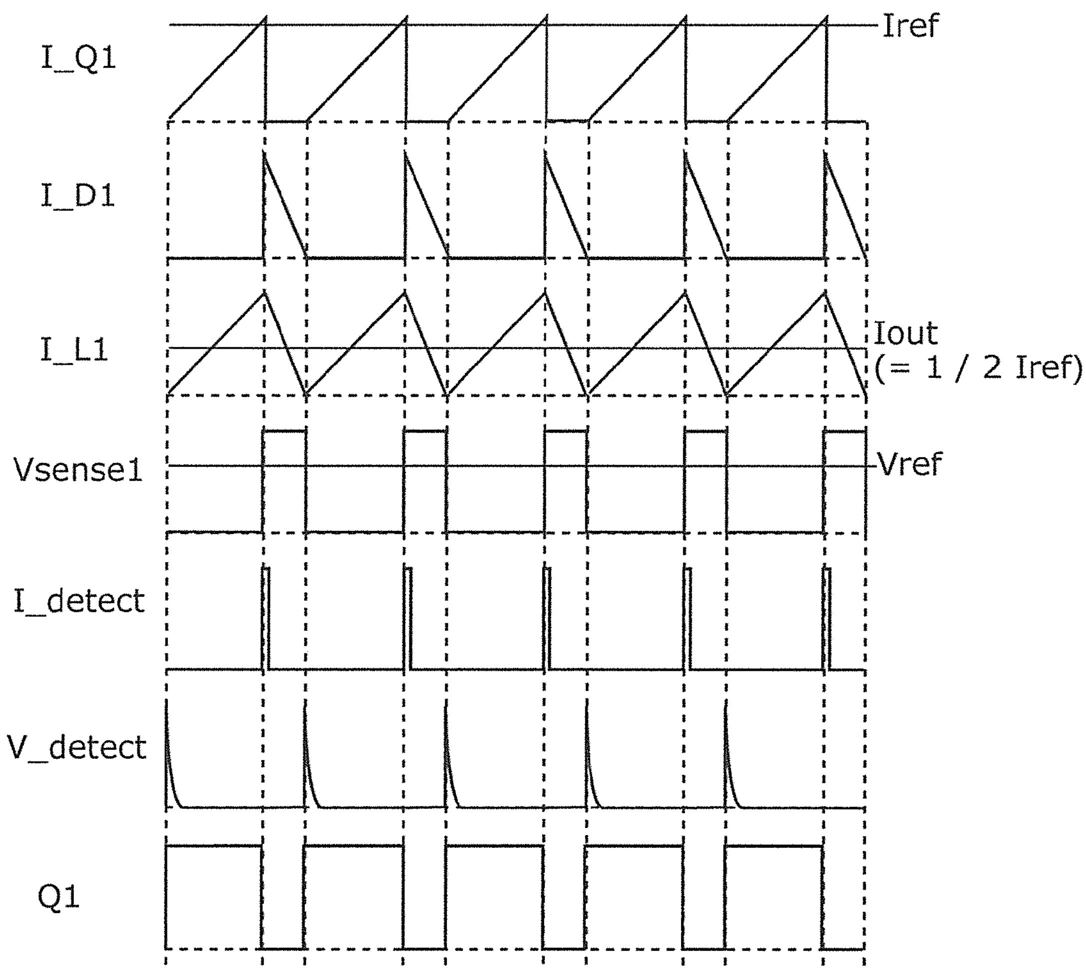


FIG. 5
PRIOR ART

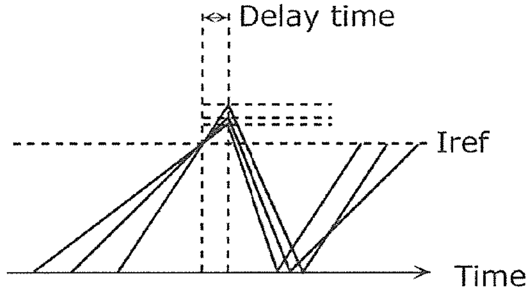


FIG. 6

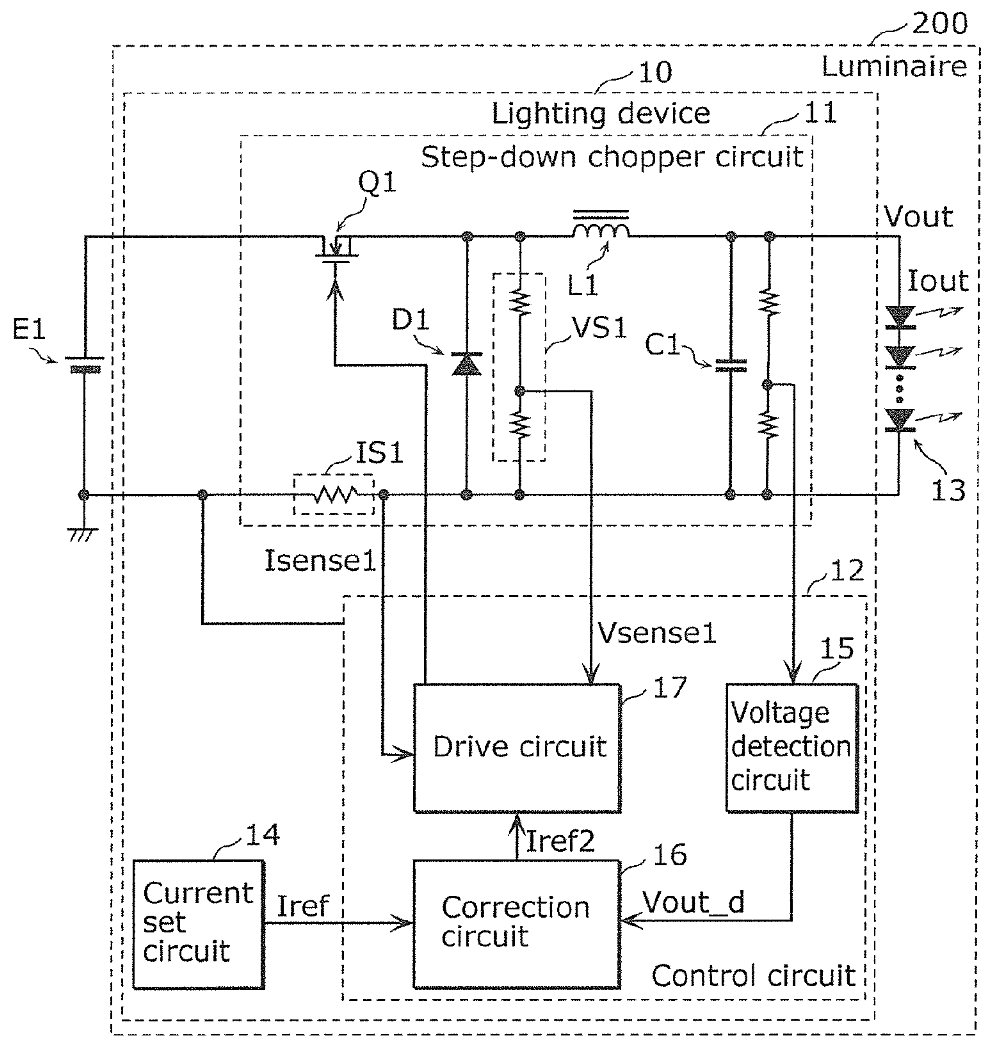


FIG. 7

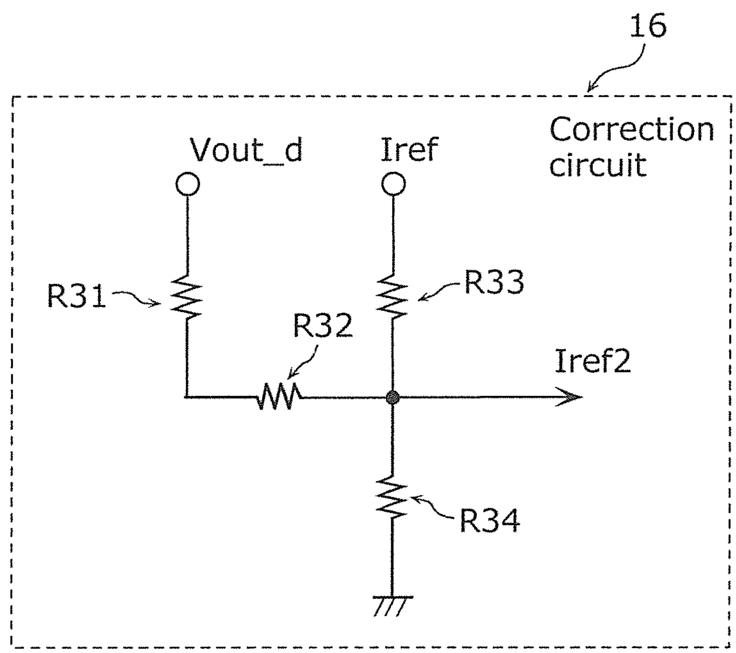

16
Correction circuit
Vout_d
Iref
R31
R32
R33
Iref2
R34

FIG. 8

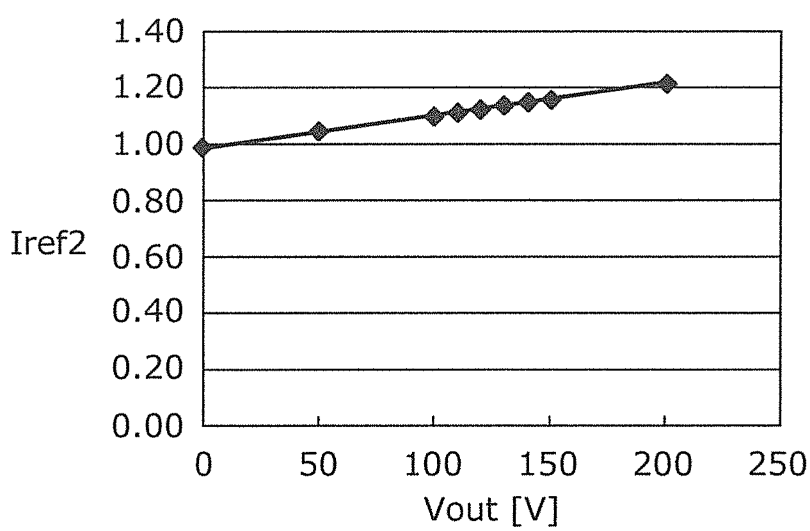

1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Iref2
0
50
100
150
200
250
Vout [V]

FIG. 9

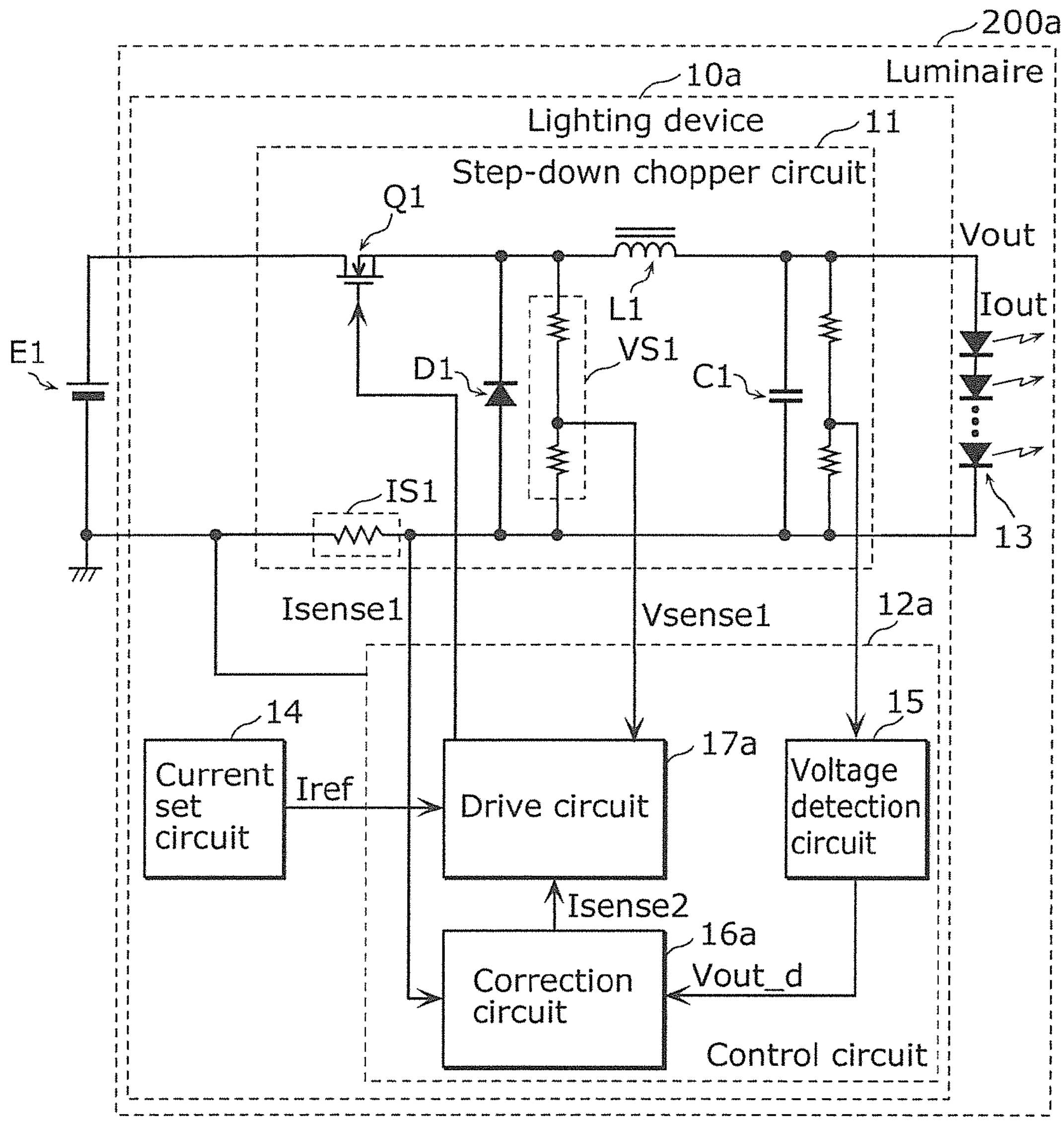

200a
Luminaire
10a
Lighting device
11
Step-down chopper circuit
Q1
Vout
L1
Iout
E1
D1
VS1
C1
IS1
13
Isense1
Vsense1
12a
14
15
17a
Current set circuit
Iref
Drive circuit
Voltage detection circuit
Isense2
16a
Vout_d
Correction circuit
Control circuit

FIG. 10

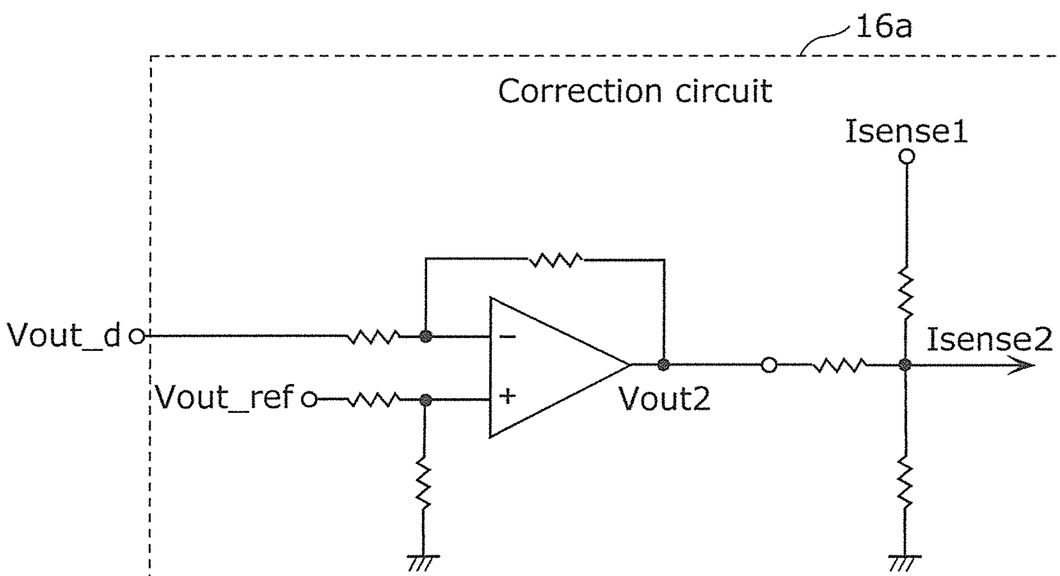

16a
Correction circuit
Isense1
Vout_d
Vout_ref
Vout2
Isense2

FIG. 11

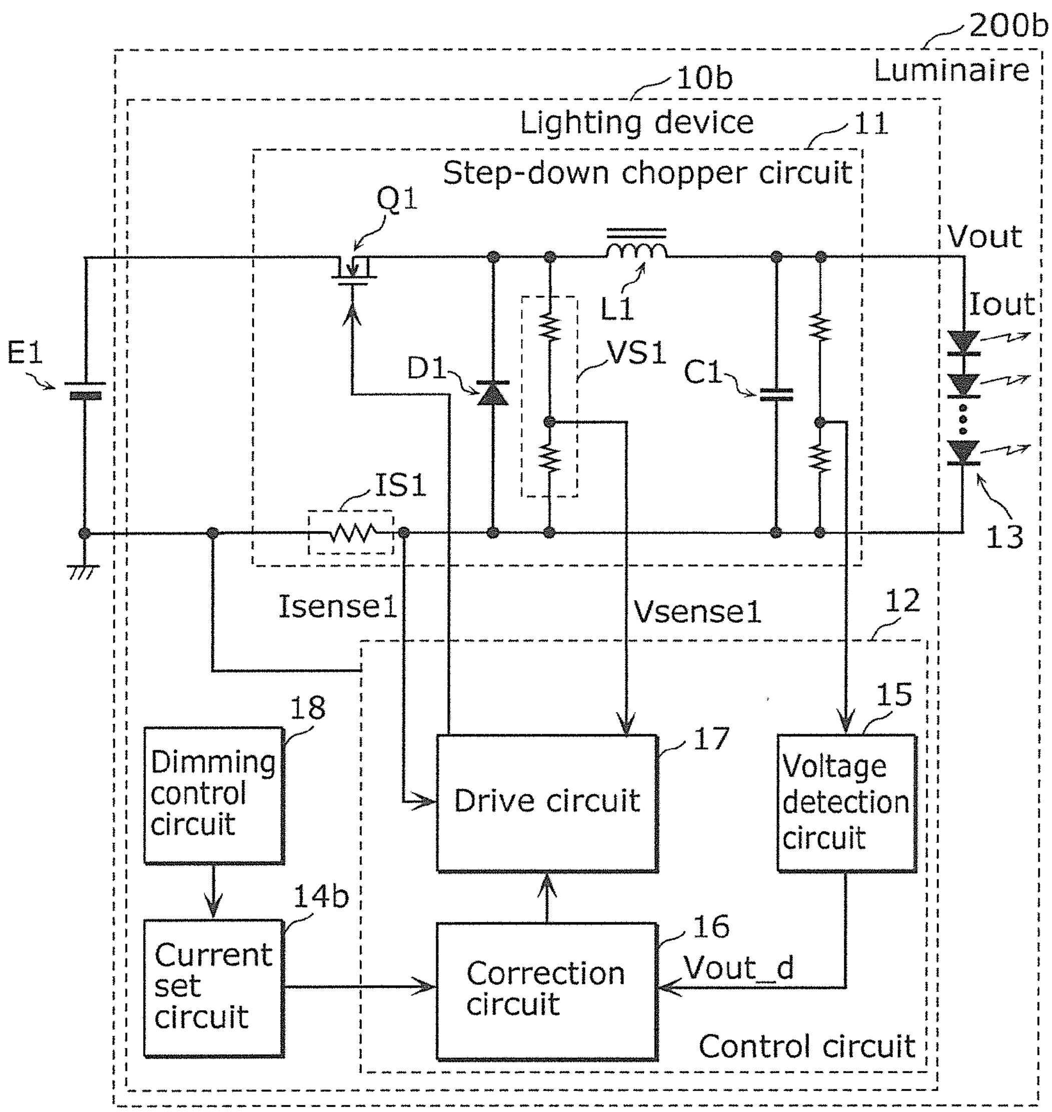

200b
Luminaire
10b
Lighting device
11
Step-down chopper circuit
Q1
L1
Vout
Iout
E1
D1
VS1
C1
IS1
13
Isense1
Vsense1
12
18
Dimming control circuit
15
17
Drive circuit
Voltage detection circuit
14b
16
Current set circuit
Correction circuit
Vout_d
Control circuit

FIG. 12

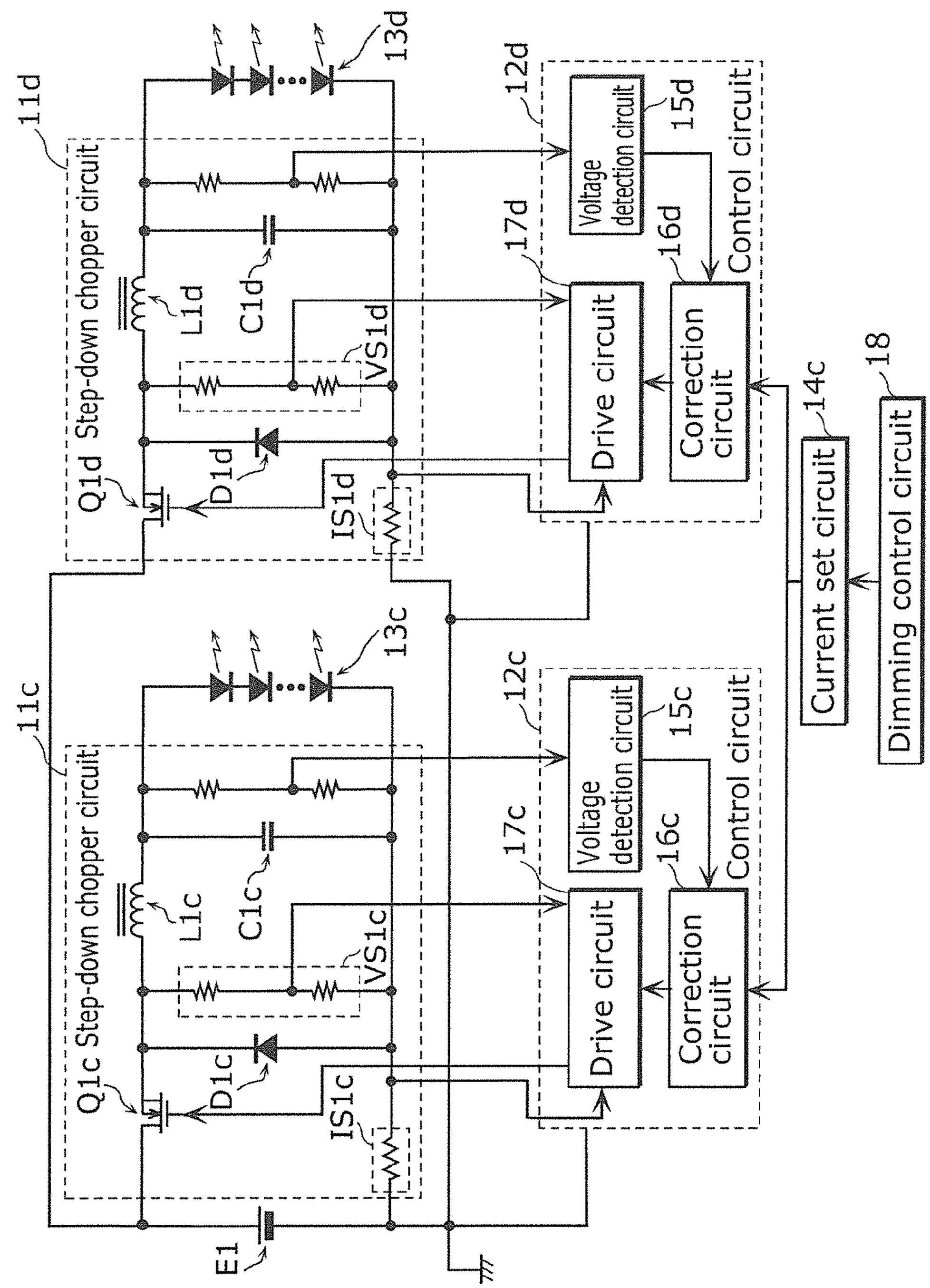

11d
Q1d Step-down chopper circuit
13d
L1d
C1d
VS1d
D1d
IS1d
12d
Voltage detection circuit
15d
16d
17d
Drive circuit
Correction circuit
Control circuit
11c
Q1c Step-down chopper circuit
13c
L1c
C1c
VS1c
D1c
IS1c
12c
Voltage detection circuit
15c
16c
17c
Drive circuit
Correction circuit
Control circuit
14c
Current set circuit
18
Dimming control circuit
E1

FIG. 13

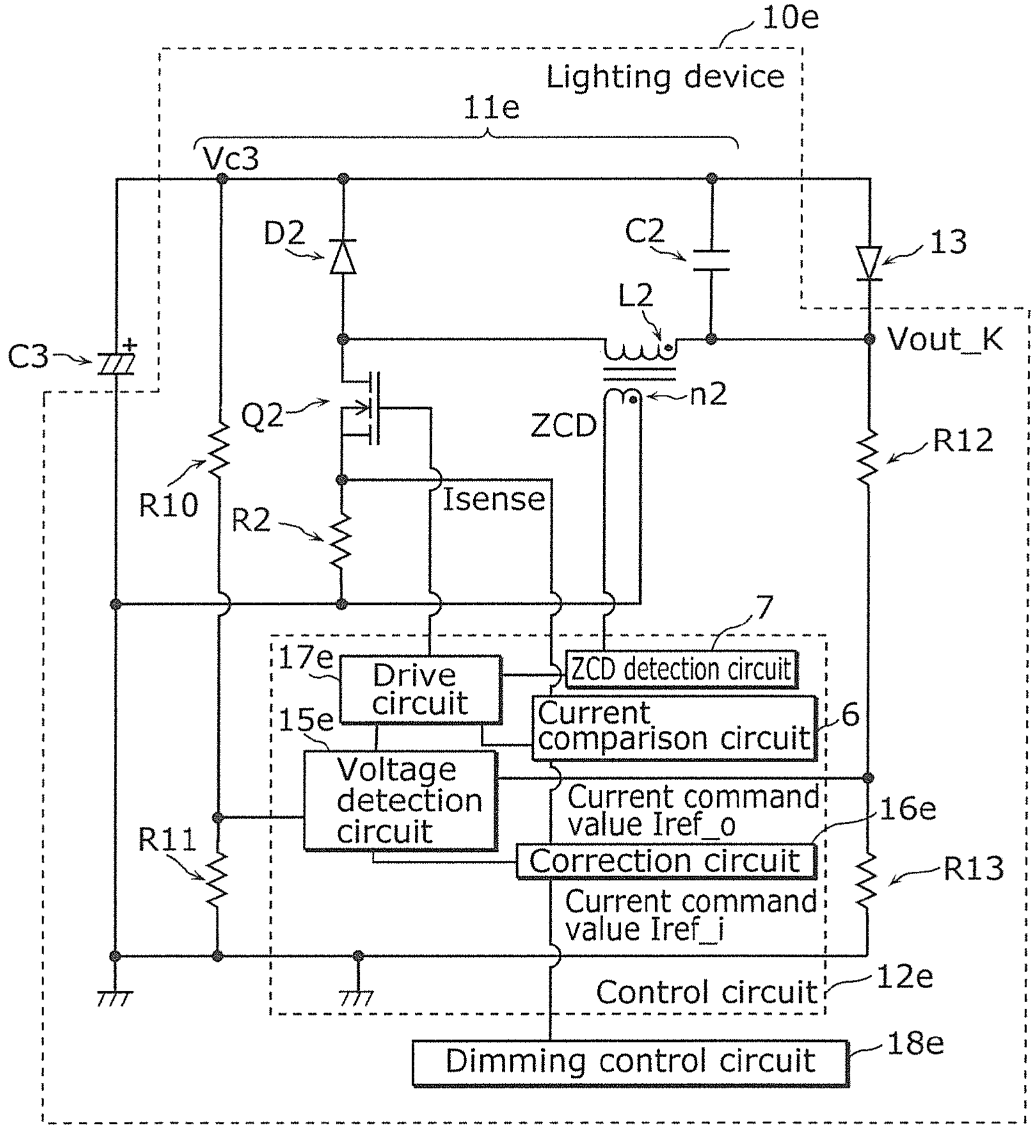

10e
Lighting device
11e
Vc3
D2
C2
13
L2
Vout_K
C3
Q2
n2
ZCD
R12
R10
Isense
R2
7
17e
Drive circuit
ZCD detection circuit
Current comparison circuit
6
15e
Voltage detection circuit
Current command value Iref_o
16e
R11
Correction circuit
R13
Current command value Iref_i
Control circuit
12e
Dimming control circuit
18e

FIG. 14

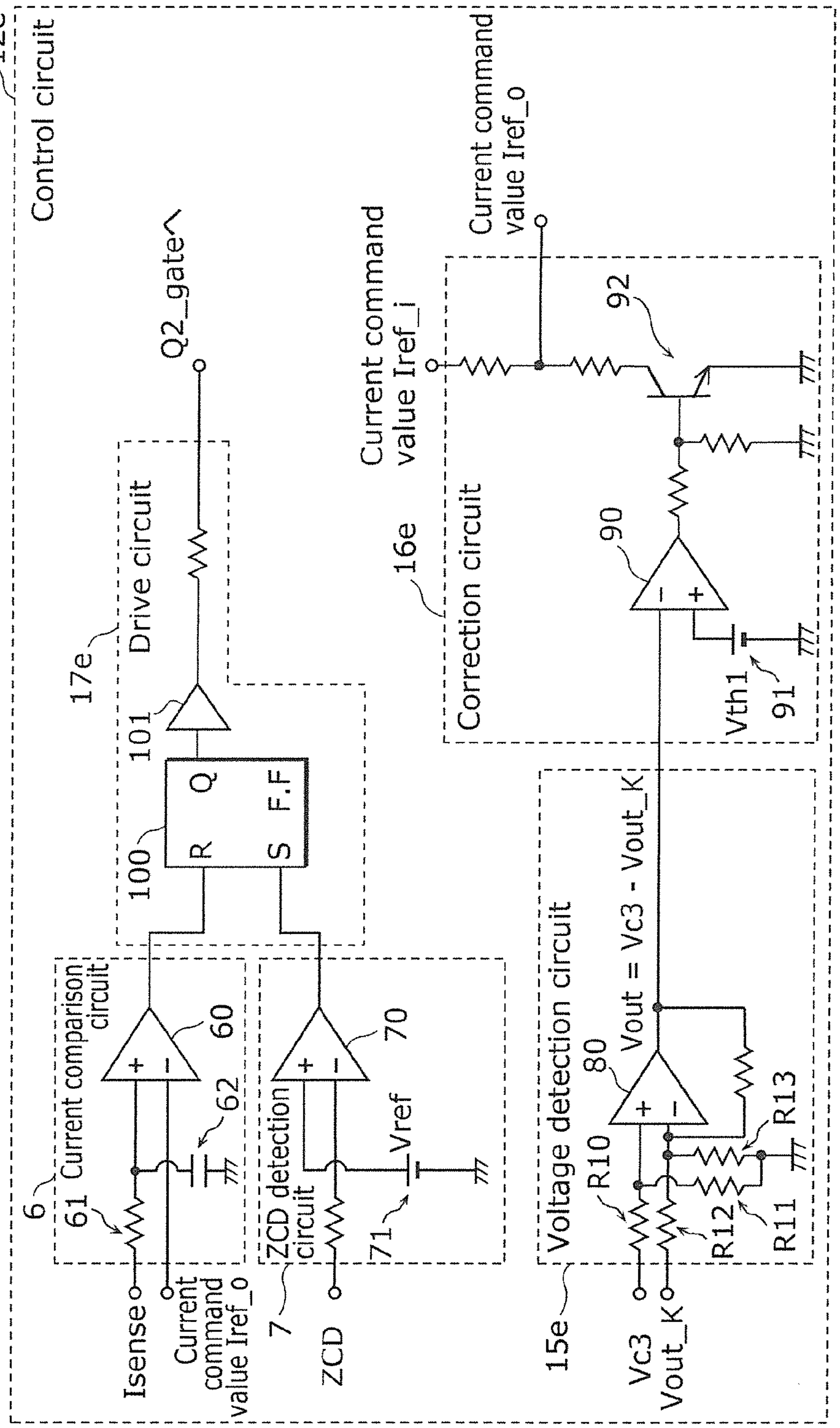

12e
Control circuit
6
Current comparison circuit
61
62
60
Isense
Current command value Iref_o
7
ZCD detection circuit
71
Vref
70
ZCD
17e
Drive circuit
100
R
S
Q
F.F
101
Q2_gate
15e
Voltage detection circuit
R10
R12
R11
R13
80
Vout = Vc3 - Vout_K
Vc3
Vout_K
16e
Correction circuit
90
91
Vth1
92
Current command value Iref_i
Current command value Iref_o

FIG. 15
PRIOR ART

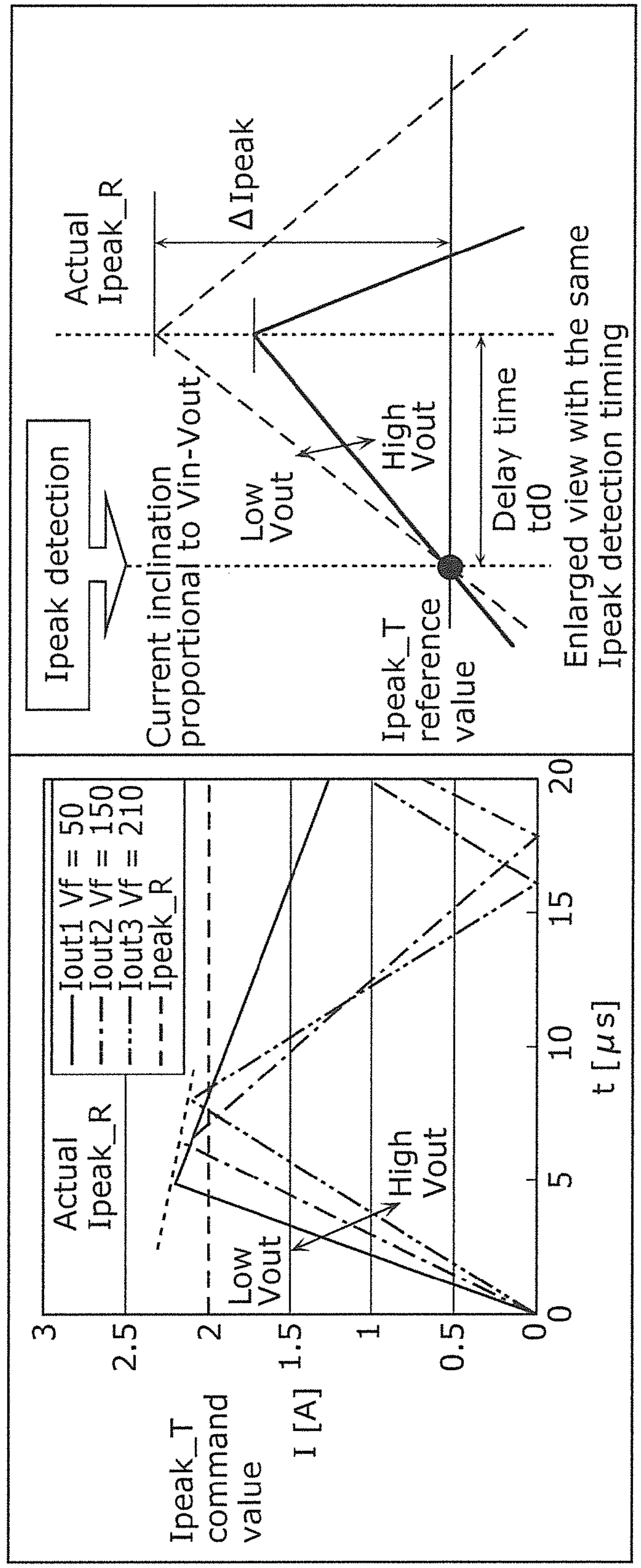


FIG. 16
PRIOR ART

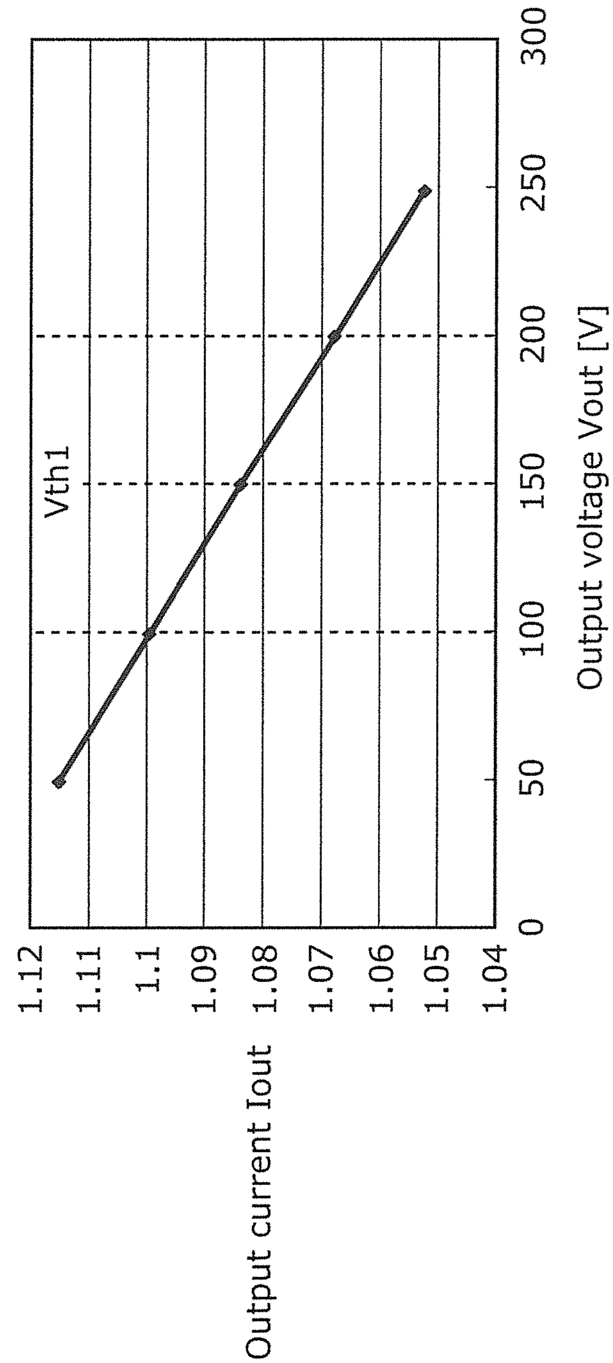


FIG. 17

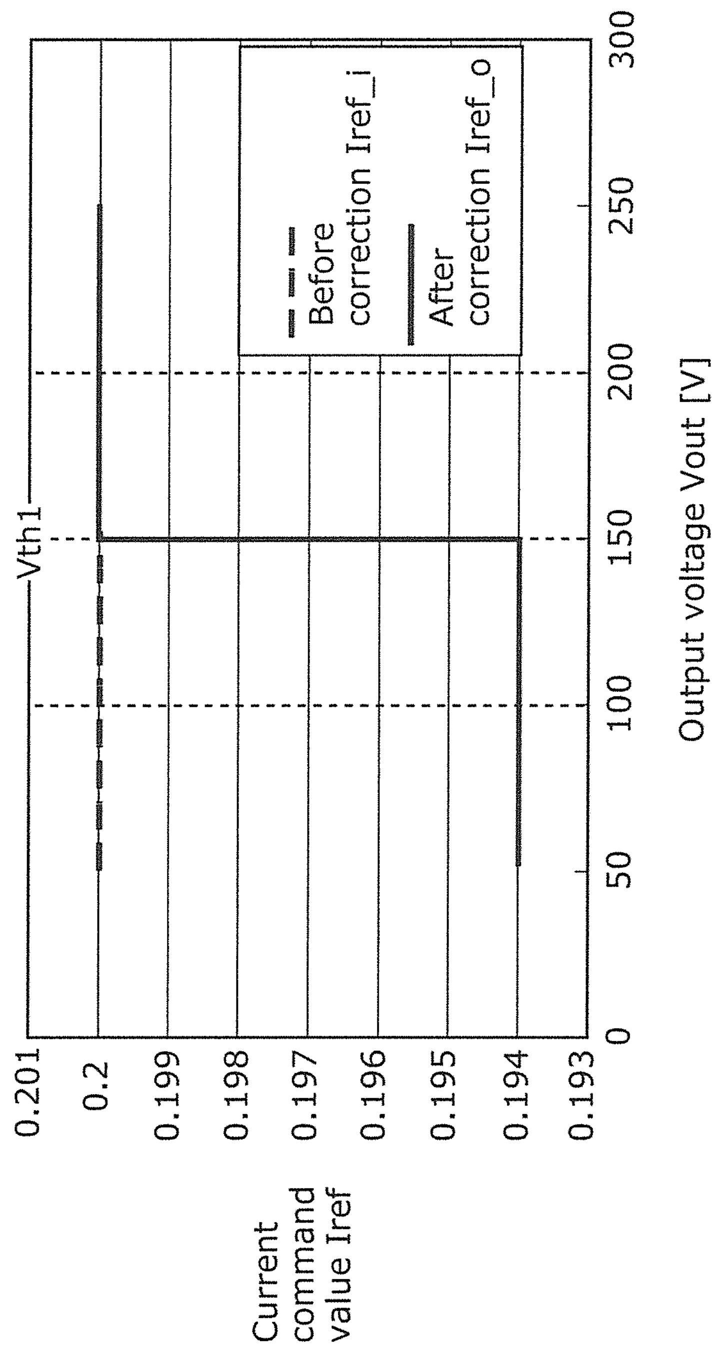
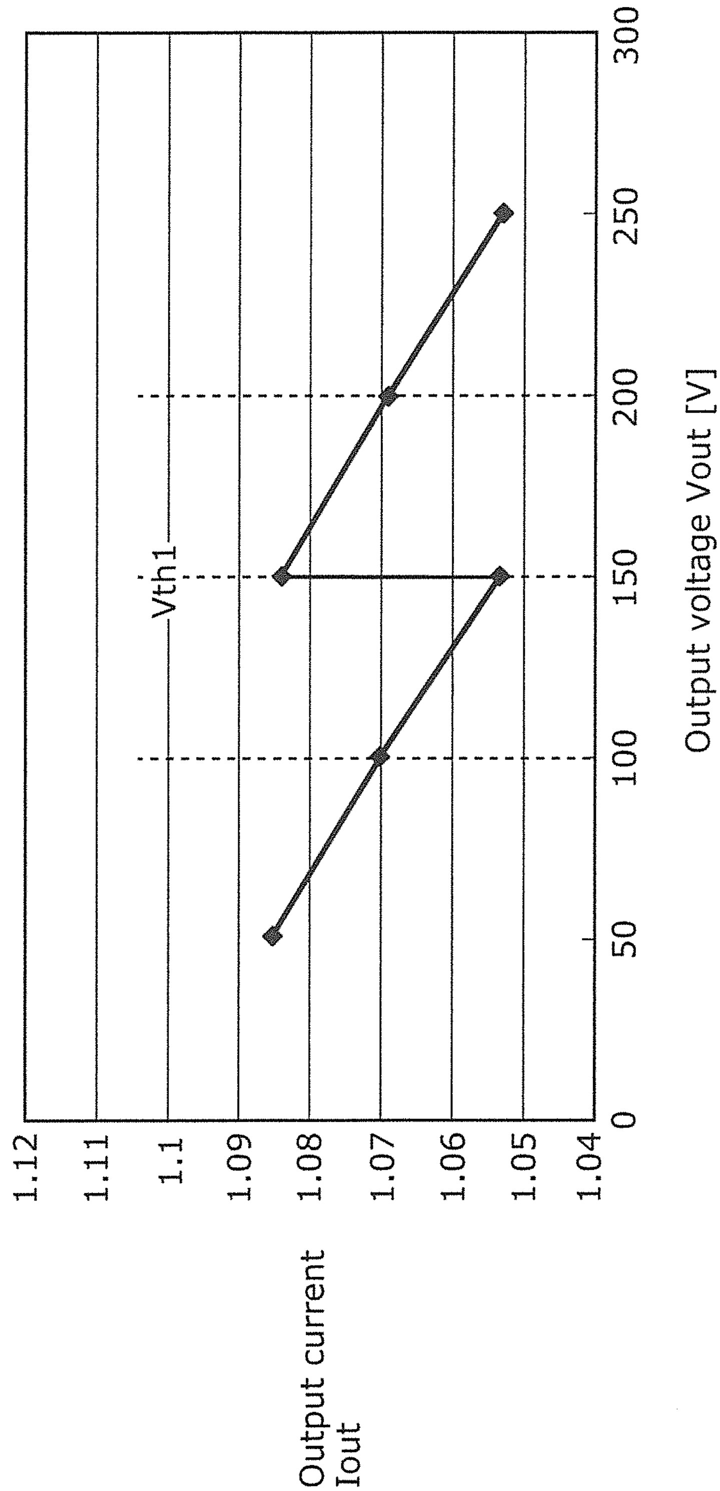
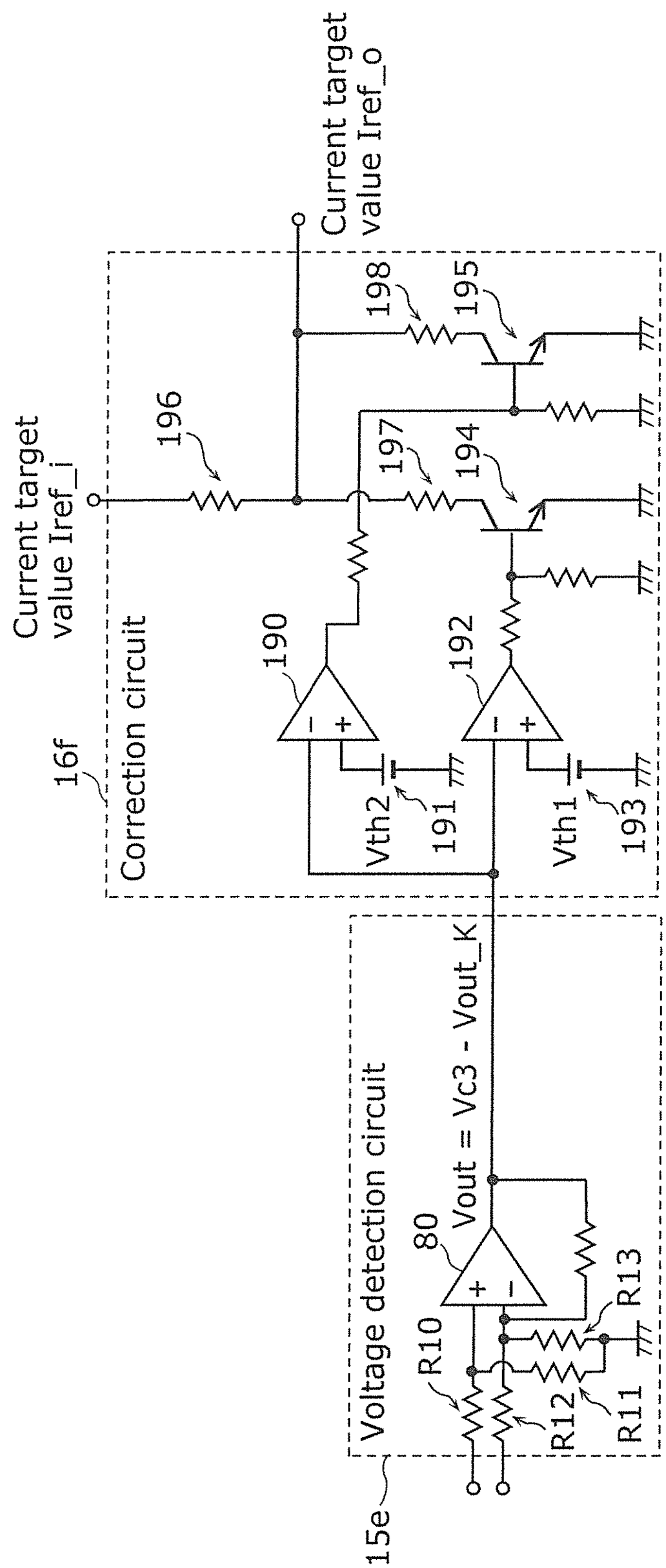

Current command value Iref
0.201
0.2
0.199
0.198
0.197
0.196
0.195
0.194
0.193
0
50
100
150
200
250
300
Output voltage Vout [V]
Vth1
Before correction Iref_i
After correction Iref_o

FIG. 18



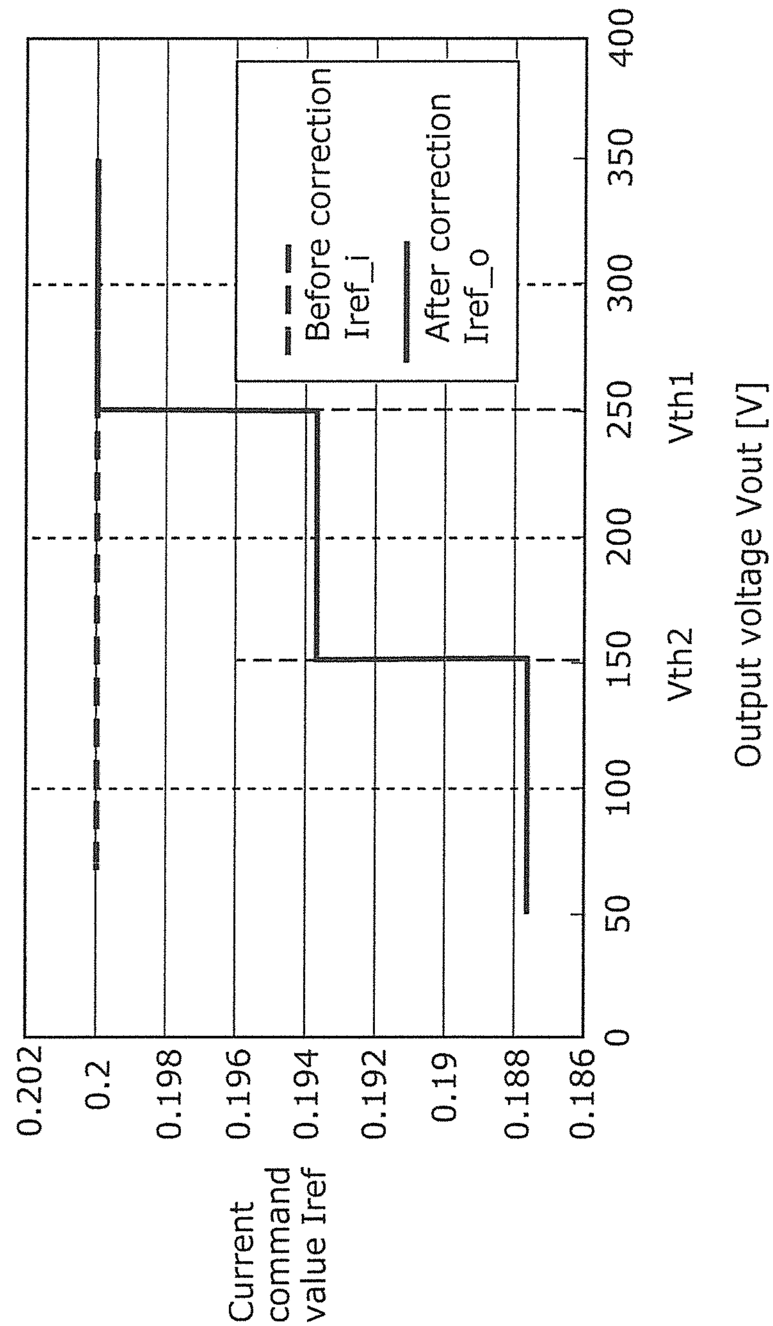
Output current
Iout
1.12
1.11
1.1
1.09
1.08
1.07
1.06
1.05
1.04
0
50
100
150
200
250
300
Vth1
Output voltage Vout [V]

FIG. 19



Current target value Iref_o
Current target value Iref_i
196
198
195
197
194
190
192
16f
Correction circuit
Vth2
191
Vth1
193
Voltage detection circuit
Vout = Vc3 - Vout_K
80
R10
R12
R11
R13
15e

FIG. 20



Current command value Iref
0.202
0.2
0.198
0.196
0.194
0.192
0.19
0.188
0.186
0
50
100
150
200
250
300
350
400
Vth2
Vth1
Output voltage Vout [V]
Before correction Iref_i
After correction Iref_o

FIG. 21

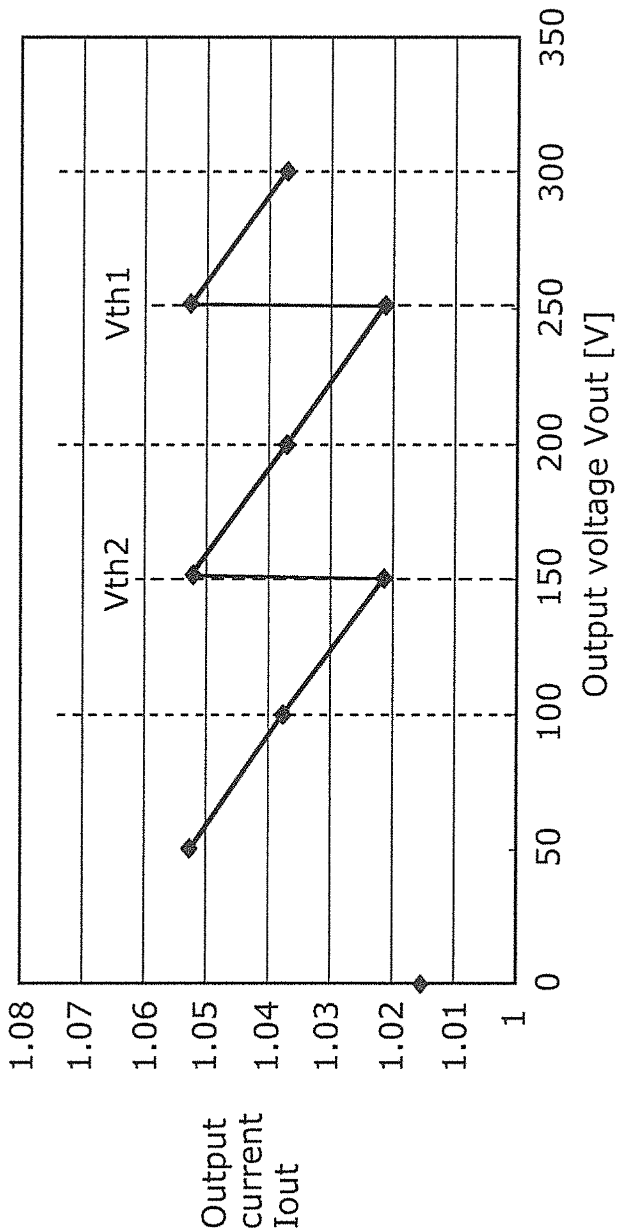

Output current Iout
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1
0
50
100
150
200
250
300
350
Output voltage Vout [V]
Vth1
Vth2

FIG. 22

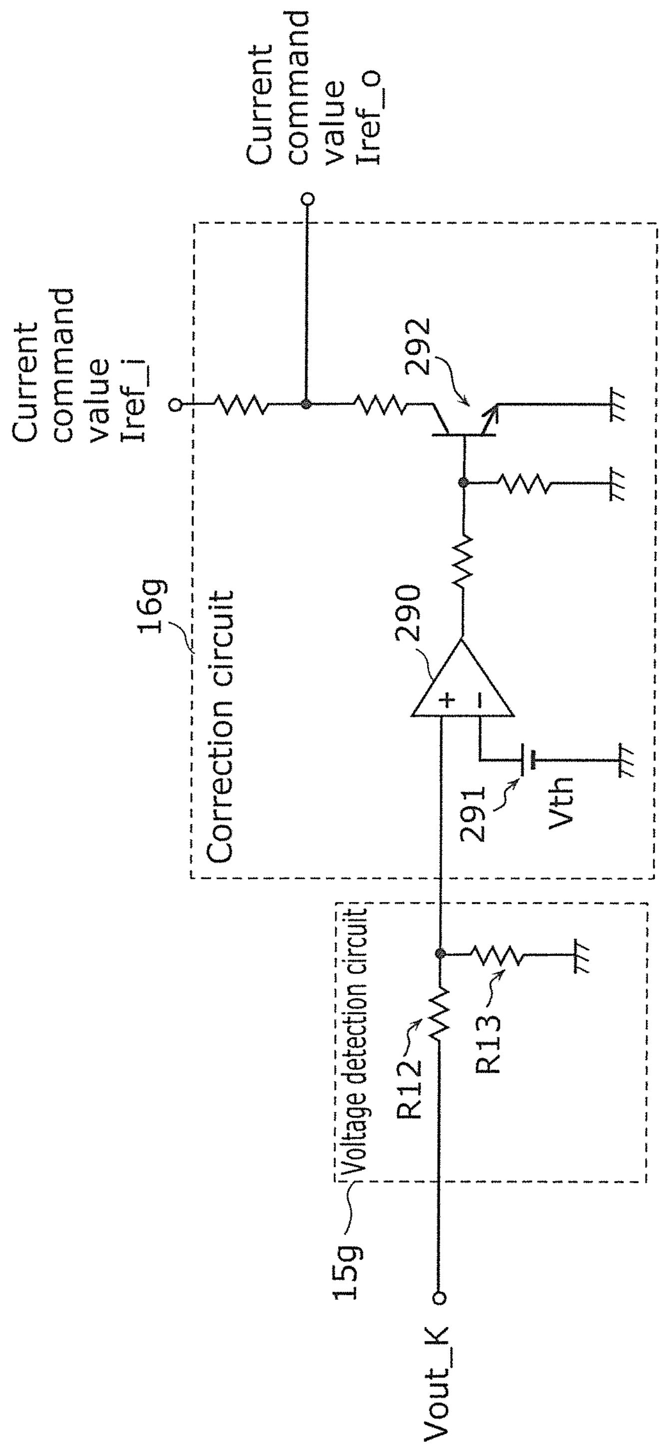

Current command value Iref_o
Current command value Iref_i
292
16g
Correction circuit
290
+
-
291
Vth
Voltage detection circuit
R12
R13
15g
Vout_K

FIG. 23

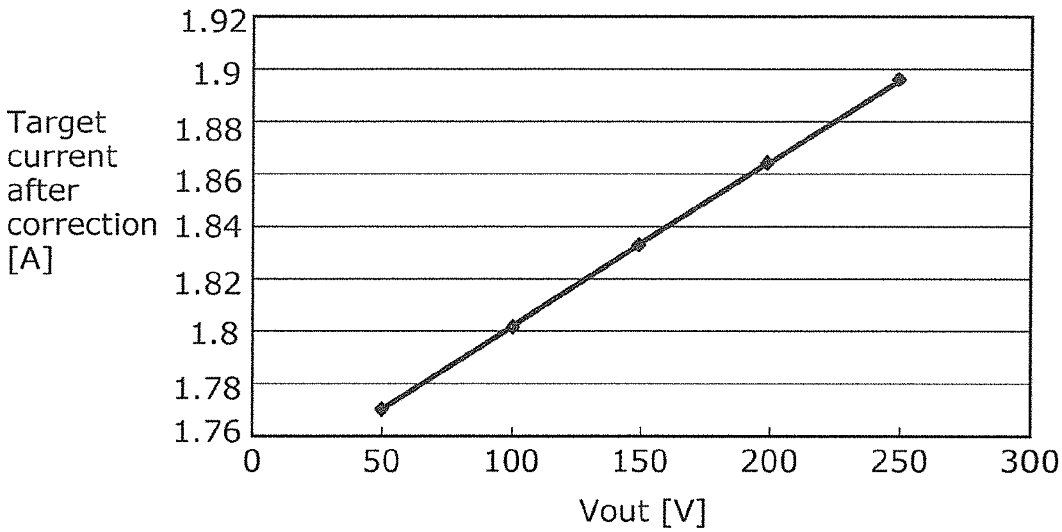

Target current after correction [A]
1.92
1.9
1.88
1.86
1.84
1.82
1.8
1.78
1.76
0
50
100
150
200
250
300
Vout [V]

FIG. 24

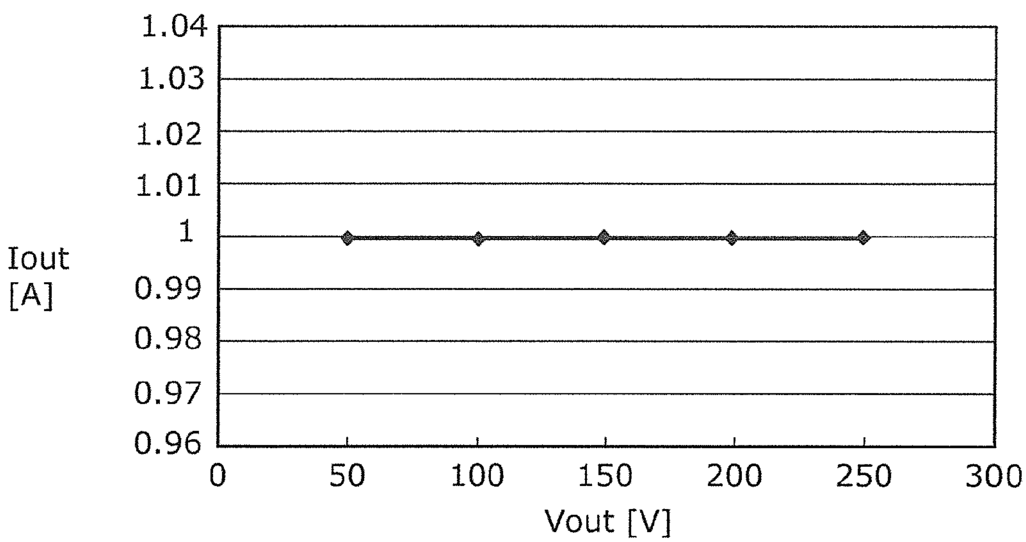

Iout [A]
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0
50
100
150
200
250
300
Vout [V]

FIG. 25

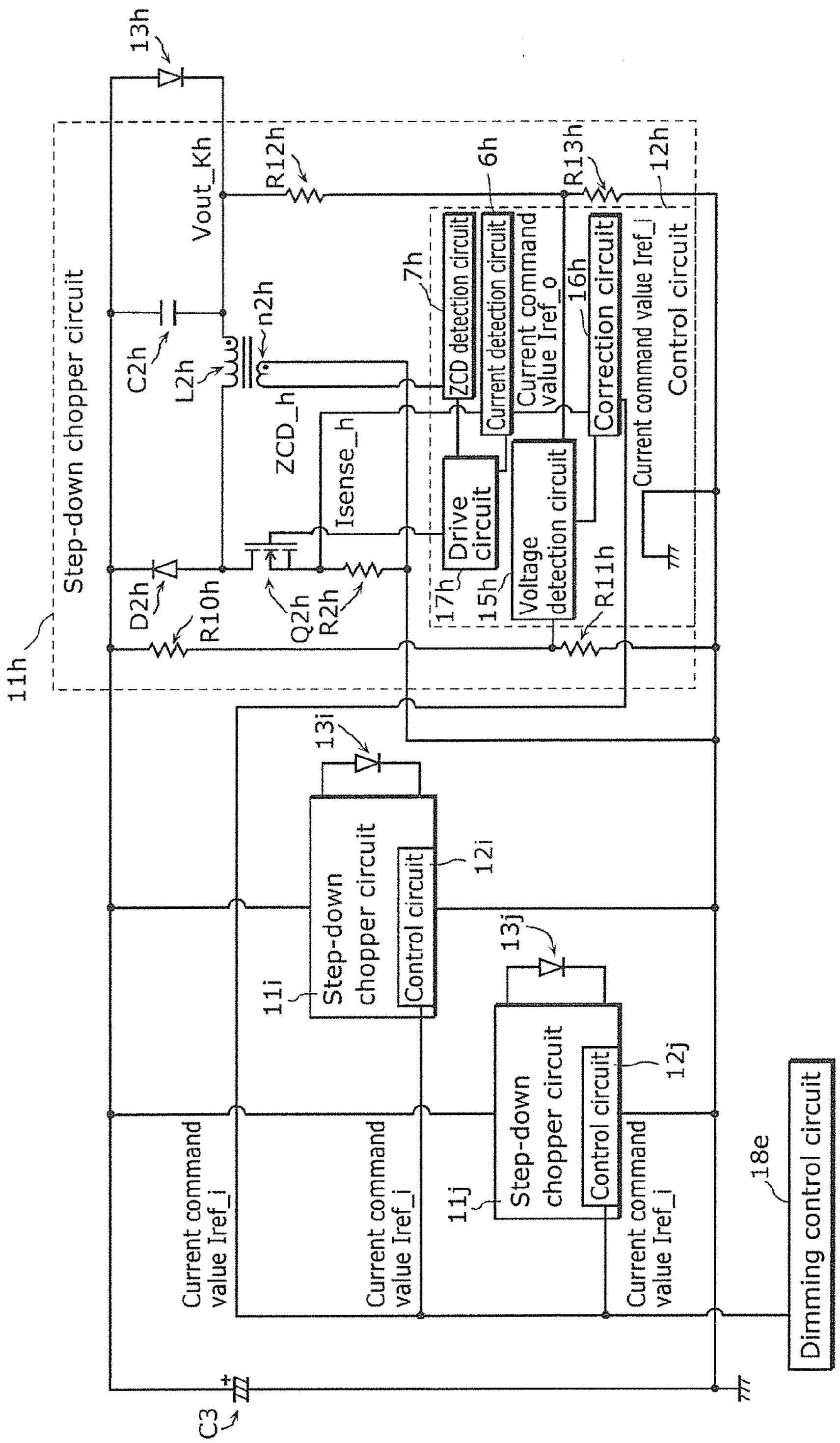
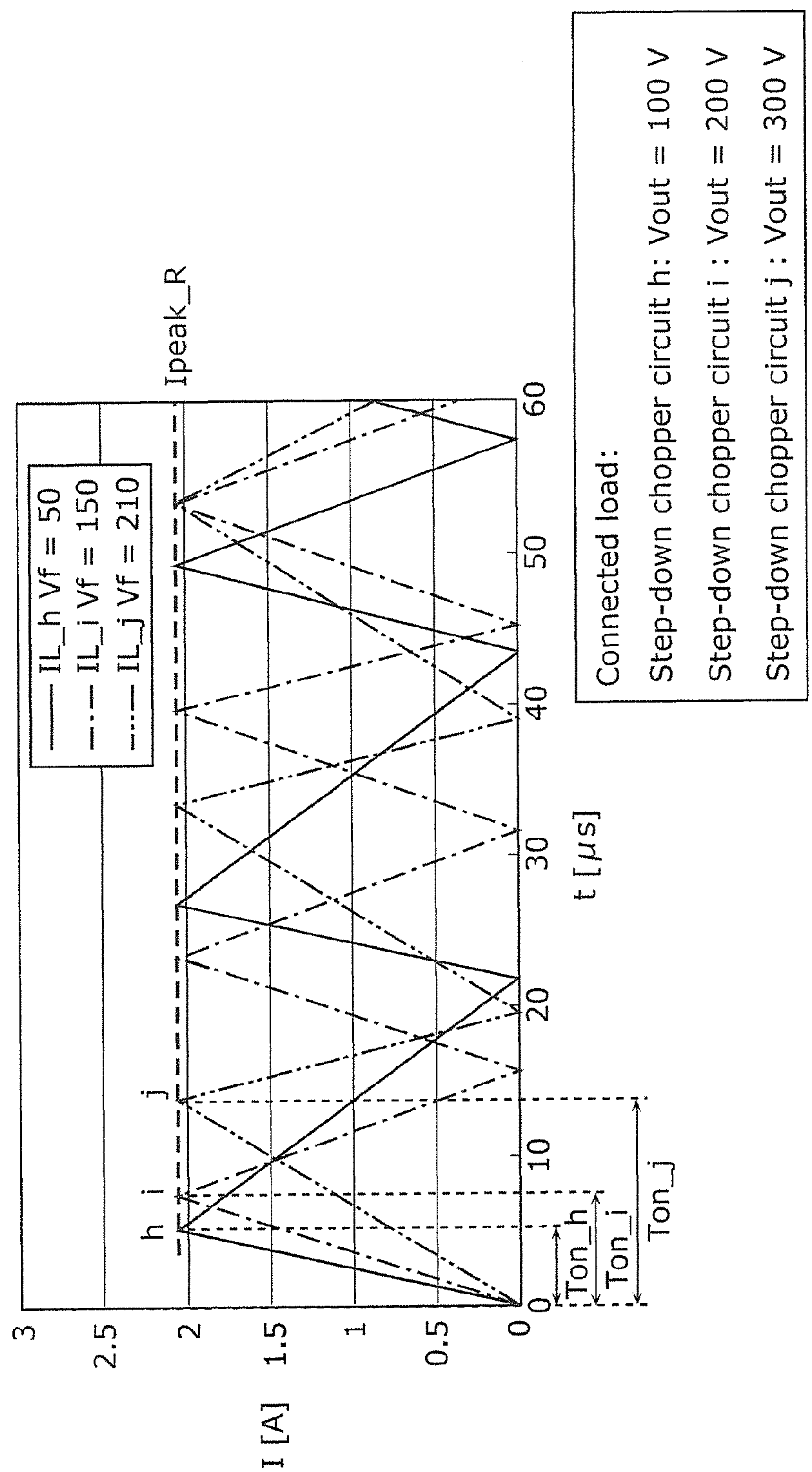

13h
Step-down chopper circuit
Vout_Kh
R12h
6h
R13h
12h
C2h
L2h
n2h
7h
ZCD detection circuit
Current detection circuit
Current command value Iref_o
16h
Correction circuit
Current command value Iref_i
Control circuit
ZCD_h
Isense_h
Drive circuit
Voltage detection circuit
R11h
17h
15h
D2h
R10h
Q2h
R2h
11h
13i
Step-down chopper circuit
Control circuit
12i
11i
13j
Step-down chopper circuit
Control circuit
12j
11j
Current command value Iref_i
Current command value Iref_i
Current command value Iref_i
18e
Dimming control circuit
C3

FIG. 26



IL_h Vf = 50
IL_i Vf = 150
IL_j Vf = 210
Ipeak_R
h
i
j
I [A]
3
2.5
2
1.5
1
0.5
0
10
20
30
40
50
60
t [μs]
Ton_h
Ton_i
Ton_j
Connected load:
Step-down chopper circuit h: Vout = 100 V
Step-down chopper circuit i : Vout = 200 V
Step-down chopper circuit j : Vout = 300 V

FIG. 27

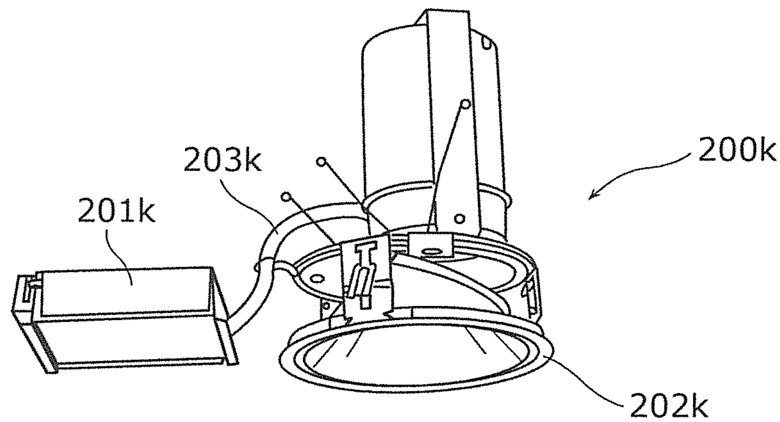


FIG. 28

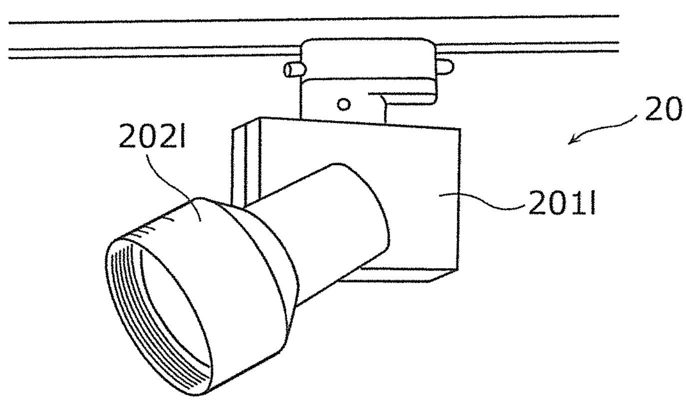
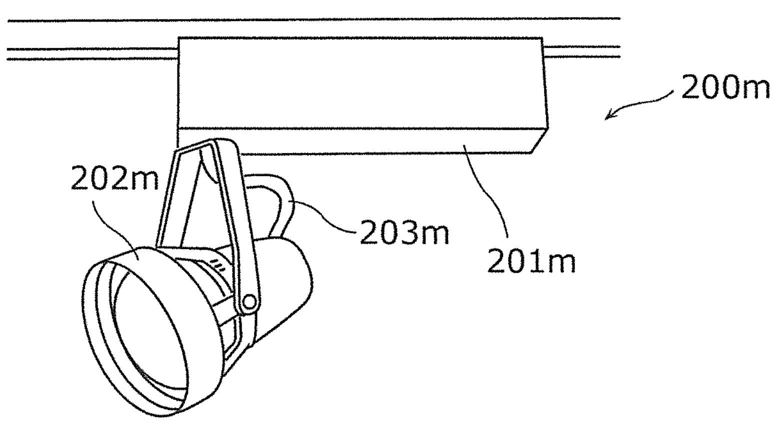


FIG. 29



LIGHTING DEVICE AND LUMINAIRE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priorities of Japanese Patent Application Number 2013-161760, filed Aug. 2, 2013, and Japanese Patent Application Number 2013-161831, filed Aug. 2, 2013, the entire content of which are hereby incorporated by reference.

TECHNICAL FIELD

The present disclosure relates to a lighting device that lights up a solid-state light-emitting element, such as a light-emitting diode (LED), and to a luminaire including the lighting device.

BACKGROUND ART

Solid-state light-emitting elements, such as LED elements, are expected to become light sources for various products due to their small size, high efficiency, and long life span.

The voltage-current characteristics of an LED element have a non-linear feature in which an electric current (hereinafter, simply referred to as current) starts flowing at a certain applied voltage or higher, and a forward voltage does not substantially change while a current near a rated current value is flowing. Hence, a light output of the LED element basically depends on a value of a current flowing through the LED element.

In illumination uses, an LED unit **1**, illustrated in FIG. **1** and including a plurality of LED elements **2** connected in series-parallel, is used as a light source, so as to obtain a light output of a predetermined luminance.

As described above, the light output of the LED element depends on a value of a current flowing through the LED element. Hence, the current value corresponding to the light output of a predetermined luminance is set as a rated current value of the LED unit **1**.

Accordingly, the lighting device that lights up the LED unit **1** is desirably controlled such that a constant current is supplied to the LED unit **1**.

FIG. **2** is a circuit diagram of an example of a lighting device for an LED unit. FIG. **2** illustrates not only the lighting device, but also a DC power source E**1** that supplies a DC power to the lighting device, and an LED unit **23** connected to the lighting device.

The lighting device includes a step-down chopper circuit **21** that is one type of a DC/DC converter, and a control circuit **22**. The step-down chopper circuit **21** includes a switching element Q**1**, an inductor L**1**, a diode D**1**, an output capacitor C**1**, and the like.

The step-down chopper circuit **21** further includes a current detection circuit IS**1** and a diode voltage detection circuit VS**1**. The current detection circuit IS**1** detects a current value Isense1 flowing through the inductor L**1**. The diode voltage detection circuit VS**1** detects a voltage value Vsense1 across the diode D**1**.

Examples of the DC power source E**1** include a DC power source that includes a commercial AC power source and a full-wave rectifier circuit, and a DC power source that includes a commercial AC power source and a power factor improvement circuit.

Now, a brief description is given of an operation of the lighting device illustrated in FIG. **2**.

When the switching element Q**1** is turned ON in response to a command from the control circuit **22**, a current flows through the LED unit **23** from the DC power source E**1** via the switching element Q**1**, the inductor L**1**, and the output capacitor C**1**. The current flowing through the inductor L**1** has a time rate of change of (Vin−Vout)/L that is determined by a voltage value Vin of the DC power source E**1**, a load voltage Vout applied to the LED unit **23**, and an inductance value L of the inductor L**1**.

The switching element Q**1** is turned OFF when the above current is detected by the current detection circuit IS**1** and a detected value Isense1 reaches a target current value Iref.

When the switching element Q**1** is turned OFF, energy stored in the inductor L**1** is released with a current supplied while the switching element Q**1** was ON.

While the energy stored in the inductor L**1** is being released, the diode D**1** is conducting. At this time, the diode has a forward voltage that has a very small value. When the diode D**1** becomes non-conducting after the energy release, the voltage across the diode D**1** rises to a value near the load voltage Vout.

The rise of the voltage across the diode D**1** is detected through detection that a voltage value Vsense1 that is an output of the diode voltage detection circuit VS**1** has exceeded a predetermined value Vref. When the rise of the voltage across the diode D**1** is detected, the control circuit **22** determines that the release of the energy stored in the inductor L**1** is finished, and turns ON the switching element Q**1** again.

FIG. **3** is a circuit diagram illustrating an example of the control circuit **22** that operates as described above.

The control circuit **22** includes comparators **31** and **32**, and an RS flip-flop.

The comparator **31** is an element that detects a current flowing through the inductor L**1**. The comparator **32** is a circuit that detects a voltage generated in the diode D**1**.

The RS flip-flop is a circuit that receives I_detect that is an output of the comparator **31** as a reset signal, and receives V_detect that is an output at a connection point **35** of the comparator **32** as a set signal. The RS flip-flop that outputs a signal to a connection point **36** is formed by NOR circuits **33** and **34** illustrated in FIG. **3**.

FIG. **4** is a timing chart illustrating operations of respective elements in the lighting device described above.

In FIG. **4**, currents flowing through the switching element Q**1**, the diode D**1**, and the inductor L**1** are respectively represented by I_Q**1**, I_D**1**, and I_L**1**.

By use of the lighting device that operates as described above, energy is continuously supplied to the lighting device, and a stable DC current is supplied from the output capacitor C**1** to the LED unit **23** serving as a load. In addition, in principle, an appropriate setting of a current peak value of the inductor L**1** allows the LED unit **23** to be lit up with a rated current.

Moreover, there are conventional techniques for enhancing stabilization of a current flowing through an LED unit. Japanese Unexamined Patent Application Publication No. 2012-109141 (hereinafter, referred to as patent literature (PTL) 1) discloses a method below performed in a lighting device including a step-down chopper circuit. Specifically, the method is performed to keep a current flowing through an LED unit constant regardless of the variations in DC power source when an energy release of an inductor is detected by a voltage generated at a secondary winding of the inductor. In the technique disclosed in PTL 1, when a switching element is OFF, the voltage generated at the secondary winding of the inductor is used to keep a current flowing through an LED unit serving as a load constant even when a DC power source varies. In this way, the variations in current due to a power source voltage is reduced.

SUMMARY

As described below, however, stabilization of the light output of the LED unit for illumination uses is insufficient. As described above, in the LED unit for illumination uses, a plurality of LED elements are connected in series-parallel and used as one light source to secure sufficient luminance. Each LED element included in the LED unit is appropriately manufactured. However, there are variations in voltage (forward voltage) applied across each LED element when a constant current flows. Hence, the LED unit including such LED elements connected in series-parallel can have significant variations in forward voltage.

The above described step-down chopper circuit is controlled such that a current has a predetermined peak value. In an actual operation, however, the components included in the step-down chopper circuit have delay time between when the current reaches the predetermined value and when the switching element **Q1** is turned OFF. Here, the variations in forward voltage of the LED unit causes an output voltage Vout of the step-down chopper circuit to be a forward voltage, so that the time rate of change of the current flowing through the inductor L**1** changes.

FIG. **5** illustrates change in current flowing through the inductor L**1** relative to time.

As FIG. **5** illustrates, different time rate of change of current with the same delay time results in different peak values obtained when the switching element **Q1** is turned OFF. Hence, different forward voltages of the LED unit results in different smoothed currents flowing through the LED unit. More specifically, in an environment that a plurality of LED units are used, the variations in light output of individual LED units may adversely cause problems such as different levels of illuminance, color unevenness, and the like.

In particular, in a power source device used for a luminaire that includes a plurality of LED units, the variations in light output of the individual LED units are a significant problem.

Japanese Unexamined Patent Application No. 2010-40509 (hereinafter, referred to as PTL 2) discloses a technique used in a lighting device that supplies electric power to a plurality of solid-state light-emitting elements. Specifically, in the technique, a current flowing through each solid-state light-emitting element is made substantially equal to each other.

In the technique disclosed in PTL 2, an output of a DC/DC convertor serving as a DC power source is connected to a plurality of buck switching regulators. Then, it is controlled such that the current values of the LED elements connected to respective buck switching regulators are equal. Each buck switching regulator includes a switching balance controller. The switching balance controller performs feedback control by using an integrator or the like so that a current flowing through a switching element of the buck switching regulator coincides with a target value. In addition, the switching balance controller includes a feedback selection circuit that regulates an output voltage of the DC/DC convertor so as to supply electric power to the buck switching regulator.

Although the technique disclosed in PTL 2 can make a current flowing through each LED current equal, the configuration is complicated, which results in problems such as an increase in system cost.

The present invention has been conceived in order to solve the above problems. An object of the present invention is to provide a lighting device that has a simple configuration and reduces variations in current flowing through solid-state light-emitting elements which are connected to the lighting device and which have different forward voltages.

In order to achieve the above object, a lighting device according to one aspect of the present invention is a lighting device that is connected to a DC power source to supply a current to a solid-state light-emitting element. The lighting device includes: a DC/DC converter; and a control circuit. The DC/DC converter includes: a switching element that is connected to the DC power source and is turned ON and OFF; an inductor that is connected in series with the switching element, and through which the current from the DC power source flows when the switching element is ON; a diode that supplies, to the solid-state light-emitting element, the current released from the inductor; and a current detection circuit that detects a current flowing through the switching element and outputs a detected current value that is a value of the current detected. The control circuit includes: a drive circuit that turns the switching element ON and OFF; a voltage detection circuit that detects either one of a voltage across the solid-state light-emitting element and a voltage across the inductor, and outputs a detected voltage value that is a value of the voltage detected; and a correction circuit that corrects a timing at which the drive circuit turns OFF the switching element. When the drive circuit detects that the inductor has finished releasing energy, the drive circuit turns ON the switching element, and when the detected current value reaches a predetermined current command value, the drive circuit turns OFF the switching element, and the correction circuit corrects the timing at which the drive circuit turns OFF the switching element, based on the detected voltage value.

Moreover, in the lighting device according to one aspect of the present invention, it may be that the correction circuit corrects the timing at which the drive circuit turns OFF the switching element, by correcting the predetermined current command value based on the detected voltage value.

Moreover, in the lighting device according to one aspect of the present invention, it may be that the correction circuit corrects the predetermined current command value such that, in a relationship between the detected voltage value and a peak value of the detected current value, the detected current value has peaks that are substantially the same in value at at least two different detected voltage values among a plurality of the detected voltage values.

Moreover, in the lighting device according to one aspect of the present invention, it may be that when the detected voltage value is less than or equal to a first threshold value, the correction circuit corrects the predetermined current command value to a first correction value that is less than the predetermined current command value.

Moreover, in the lighting device according to one aspect of the present invention, it may be that when the detected voltage value is less than or equal to a second threshold value that is less than the first threshold value, the correction circuit further corrects the predetermined current command value to a second correction value that is less than the first correction value.

Moreover, in the lighting device according to one aspect of the present invention, it may be that the first threshold value and the second threshold value fall between values of different forward voltages of two solid-state light-emitting elements among a plurality of the solid-state light-emitting elements to be connected to the lighting device.

Moreover, in the lighting device according to one aspect of the present invention, it may be that the correction circuit corrects the predetermined current command value such that a peak value of the current flowing through the inductor is constant regardless of the voltage detected by the voltage detection circuit.

Moreover, in the lighting device according to one aspect of the present invention, it may be that the correction circuit corrects the predetermined current command value such that the predetermined current command value after correction has a positive correlation with the detected voltage value.

In the lighting device according to one aspect of the present invention, it may be that the correction circuit corrects the timing at which the drive circuit turns OFF the switching element, by correcting the detected current value based on the detected voltage value.

Moreover, in the lighting device according to one aspect of the present invention, it may be that the correction circuit corrects the detected current value such that the detected current value after correction has a negative correlation with the detected voltage value.

Moreover, the lighting device according to one aspect of the present invention may include a plurality of sets each including the DC/DC converter and the control circuit.

Moreover, the lighting device according to aspect of the present invention may further include a dimming control circuit that changes the predetermined current command value.

Moreover, a luminaire according to one aspect of the present invention include the lighting device; and a solid-state light-emitting element.

According to one aspect of the present invention, it is possible to provide a lighting device that has a simple configuration and reduces variations in current flowing through solid-state light-emitting elements connected to the lighting device and which have different forward voltages.

BRIEF DESCRIPTION OF THE DRAWINGS

The figures depict one or more implementations in accordance with the present teaching, by way of examples only, not by way of limitations. In the figures, like reference numerals refer to the same or similar elements.

FIG. **1** illustrates an external appearance of an LED unit that includes a plurality of LED elements connected in series-parallel.

FIG. **2** is a circuit diagram of a lighting device of a background art.

FIG. **3** is a circuit diagram of a control circuit included in the lighting device of the background art.

FIG. **4** is a timing chart illustrating operations of respective elements included in the lighting device of the background art.

FIG. **5** illustrates temporal change in current flowing through an inductor included in the lighting device of the background art.

FIG. **6** is a circuit diagram of a lighting device and a luminaire according to Embodiment 1.

FIG. **7** is a circuit diagram of a correction circuit according to Embodiment 1.

FIG. **8** is a graph showing a relationship between Vout and Iref2 in the lighting device according to Embodiment 1.

FIG. **9** is a circuit diagram of a lighting device and a luminaire according to Embodiment 2.

FIG. **10** is a circuit diagram of a correction circuit according to Embodiment 2.

FIG. **11** is a circuit diagram of a lighting device and a luminaire according to Embodiment 3.

FIG. **12** is a circuit diagram of a lighting device according to Embodiment 4.

FIG. **13** is a circuit diagram of a lighting device according to Embodiment 5.

FIG. **14** is a detailed circuit diagram of a control circuit included in a lighting device according to Embodiment 5.

FIG. **15** illustrates variations in peak value of a current flowing through an inductor included in a lighting device of a background art.

FIG. **16** illustrates output voltage-current characteristics in the lighting device of the background art.

FIG. **17** illustrates a relationship between an output voltage and a current command value in the lighting device according to Embodiment 5.

FIG. **18** illustrates output voltage-current characteristics in the lighting device according to Embodiment 5.

FIG. **19** is a detailed circuit diagram of a correction circuit according to Embodiment 6.

FIG. **20** illustrates a relationship between an output voltage and a current command value in a lighting device according to Embodiment 6.

FIG. **21** illustrates output voltage-current characteristics in the lighting device according to Embodiment 6.

FIG. **22** is a detailed circuit diagram of a voltage detection circuit and a correction circuit according to Embodiment 7.

FIG. **23** illustrates a relationship between an output voltage and a current command value in a lighting device according to Embodiment 7.

FIG. **24** illustrates output voltage-current characteristics in the lighting device according to Embodiment 7.

FIG. **25** is a circuit diagram of a lighting device according to Embodiment 8.

FIG. **26** illustrates exemplary waveforms of currents flowing through inductors in respective buck converters in the lighting device according to Embodiment 8.

FIG. **27** illustrates an external appearance of an example of a luminaire according to Embodiment 9.

FIG. **28** illustrates an external appearance of another example of the luminaire according to Embodiment 9.

FIG. **29** illustrates an external appearance of another example of the luminaire according to Embodiment 9.

DETAILED DESCRIPTION

In the following, a lighting device and a luminaire according to embodiments of the present invention will be described, with reference to accompanying drawings. It should be noted that any of the embodiments described below will illustrate one specific preferable example of the present invention. The numerical values, shapes, materials, structural components, the arrangement and connection of the structural components, steps and the order of the steps mentioned in the following embodiments are merely an example and not intended to limit the present invention. Among the structural components in the following embodiments, the one that is not recited in any independent claim exhibiting the most generic concept of the present invention will be described as an arbitrary structural component.

It should be noted that the Drawings are schematic drawings, and are not necessarily exact depictions.

Embodiment 1

First, a lighting device and a luminaire according to Embodiment 1 of the present invention will be described.

FIG. **6** is a schematic circuit diagram of a lighting device **10** and a luminaire **200** according to Embodiment 1. FIG. **1** illustrates not only the lighting device **10** and the luminaire **200**, but also a DC power source E**1** that supplies DC power to the lighting device **10**.

The luminaire **200** includes: the lighting device **10**; and an LED unit **13** including an LED element that is one type of a solid-state light-emitting element. The LED unit **13** may be a single LED chip, or an LED module that includes a plurality of LEDs connected in series, in parallel, or in series-parallel.

The lighting device **10** includes: a step-down chopper circuit **11** that is one type of a DC/DC converter; a control circuit **12**; and a current set circuit **14**.

The step-down chopper circuit **11** includes a switching element Q**1**, an inductor L**1**, a diode D**1**, an output capacitor C**1**, a current detection circuit IS**1**, and a diode voltage detection circuit VS**1**.

The switching element Q**1** is an element connected to the DC power source E**1**, and is turned ON and Off.

The inductor L**1** is connected in series with the switching element Q**1**. A current from the DC power source E**1** flows through the inductor L**1** when the switching element Q**1** is ON.

The diode D**1** is an element that supplies, to the LED unit **13**, a current released from the inductor L**1**.

The output capacitor C**1** is an element that smoothes the current supplied to the LED unit **13**.

The current detection circuit IS**1** is a circuit that detects the current flowing through the inductor L**1**, and outputs a detected current value Isense1.

The diode voltage detection circuit VS**1** is a circuit that detects a voltage across a diode, and outputs a detected value Vsense1.

The control circuit **12** includes a drive circuit **17**, a voltage detection circuit **15**, and a correction circuit **16**.

The drive circuit **17** is a circuit that turns the switching element Q**1** ON and OFF. When the drive circuit **17** detects that the inductor L**1** has finished releasing energy, the drive circuit **17** turns ON the switching element Q**1**. When the detected current value Isense1 reaches a predetermined current command value, the drive circuit **17** turns OFF the switching element Q**1**.

The voltage detection circuit **15** is a circuit that detects a voltage across the LED unit **13**, and outputs a detected voltage value Vout_d.

The correction circuit **16** is a circuit that corrects the timing at which the drive circuit **17** turns OFF the switching element Q**1** based on the detected voltage value Vout_d. The correction is performed such that an average current flowing through the inductor L**1** has a value within a predetermined range regardless of the detected voltage value Vout_d.

The current set circuit **14** is a circuit that outputs, to the control circuit **12**, a signal indicating a current command value that is a target value of the peak value of a current flowing through the inductor L**1**.

FIG. **7** is a circuit diagram illustrating an example of the correction circuit **16** illustrated in FIG. **6**.

The correction circuit **16** illustrated in FIG. **7** includes resistors R**31**, R**32**, R**33**, and R**34**.

FIG. **8** illustrates a relationship between a corrected current command value Iref2 and a voltage Vout across the LED unit **13** obtained when a predetermined current command value Iref and the detected value Vout_d of the voltage across the LED unit **13** are inputted to the correction circuit **16** illustrated in FIG. **7**.

As FIG. **8** illustrates, when the voltage Vout across the LED unit **13** increases, the corrected current command value Iref2 increases.

Next, a description is given of an operation of the lighting device **10** according to Embodiment 1 configured as above.

When the switching element Q**1** is turned ON by the drive circuit **17**, a current from the DC power source E**1** flows through the LED unit **13** via the switching element Q**1**, the inductor L**1**, and the output capacitor C**1**. Here, as described in the background art section referring to FIG. **2**, the current flowing through the inductor L**1** has a time rate of change that depends on the voltage across the LED unit **13**.

The current flowing through the inductor L**1** is detected by the current detection circuit IS**1**, and the Isense1 that is a detected value is inputted to the drive circuit **17**.

The voltage across the LED unit **13** is detected by the voltage detection circuit **15**, and the detected value Vout_d is inputted to the correction circuit **16**. Furthermore, a current command value Iref is inputted from the current set circuit **14** to the correction circuit **16**.

The correction circuit **16** corrects the current command value Iref based on the detected value Vout_d to generate a corrected current command value Iref2, and outputs the corrected current command value Iref2 to the drive circuit **17**.

The drive circuit **17** compares the corrected current command value Iref2 and the detected value Isense1 of the current flowing through the inductor L**1**. When the drive circuit **17** detects that the Isense 1 has reached the Iref2, the drive circuit **17** switches the switching element Q**1** from ON to OFF.

As described above, the corrected current command value Iref2 increases as the detected value Vout_d increases. In other words, the time rate of change of the current flowing through the inductor L**1** decreases as the detected value Vout_d increases. Hence, the Iref2 increases as the time rate of change of the current flowing through the inductor L**1** decreases. Accordingly, for example, when the Vout_d increases, the current command value is corrected to the Iref2 that is a value greater than the current command value Iref before correction. As a result, the peak value of the current flowing through the inductor L**1** increases. In other words, it is possible to reduce variations in peak value of the current flowing through the inductor L**1** when the Vout_d varies.

When the switching element Q**1** is turned OFF, the energy stored in the inductor L**1** is released. The drive circuit **17** switches the switching element Q**1** from OFF to ON when the drive circuit **17** detects through the voltage value Vsense1 that the inductor L**1** has finished releasing energy. The voltage value Vsense1 is an output of the diode voltage detection circuit VS**1**.

The lighting device **10** can keep the current flowing through the LED unit **13** constant by the operation as above.

Embodiment 2

Next, a lighting device and a luminaire according to Embodiment 2 will be described.

FIG. **9** is a schematic circuit diagram of a lighting device **10***a* and a luminaire **200***a* according to Embodiment 2.

Embodiment 2 is different from Embodiment 1 in that a correction circuit **16***a* in a control circuit **12***a* corrects the detected value Isense1 of the current detection circuit IS**1** and outputs a corrected detected current value Isense2.

FIG. **10** is a circuit diagram illustrating an example of the correction circuit **16***a*.

As FIG. **10** illustrates, the correction circuit **16***a* constitutes a subtraction circuit.

The correction circuit **16***a* receives a detected value Vout_d of a voltage across the LED unit **13**, a reference voltage value Vout_ref, and a detected current value Isense1. When the Vout_d and the Vout_ref are inputted to the subtraction circuit of the correction circuit **16***a*, a signal Vout2 which decreases as the Vout_d increases is outputted from the subtraction circuit to the drive circuit **17***a*.

Accordingly, the correction circuit **16***a* illustrated in FIG. **10** is capable of generating the Isense2 that decreases as the Vout_d increases.

In Embodiment 2, when the Vout_d increases, the time rate of change of the current flowing through the inductor L**1** decreases. However, the detected current value is corrected to a smaller value, delaying the timing at which the switching element Q**1** is turned OFF. Hence, it is possible to reduce that the peak value of the current flowing through the inductor L**1** decreases when the Vout_d increases.

The lighting device **10***a* can keep the current flowing through the LED unit **13** constant by the operation as above.

Embodiment 3

Next, a lighting device and a luminaire according to Embodiment 3 will be described.

FIG. **11** is a schematic circuit diagram of a lighting device **10***b* and a luminaire **200***b* according to Embodiment 3.

The lighting device **10***b* according to Embodiment 3 is different from Embodiment 1 in that a dimming control circuit **18** is included.

The dimming control circuit **18** is a circuit that can dim the LED unit **13** by changing an Iref that is an output of a current set circuit **14***b*.

The lighting device **10***b* reduces unnecessary variations in light output of the LED unit **13** that is caused by variations in voltage across the LED unit **13** during dimming by the dimming control circuit **18**. As a result, appropriate dimming can be achieved.

In Embodiment 3, the dimming control circuit **18** is added to the lighting device **10** according to Embodiment 1. It may also be that the dimming control circuit **18** is added to the lighting device **10***a* according to Embodiment 2.

Embodiment 4

Next, a lighting device and a luminaire according to Embodiment 4 will be described.

FIG. **12** is a schematic circuit diagram of a lighting device according to Embodiment 4.

Embodiment 4 is different from Embodiment 3 in that the lighting device includes two step-down chopper circuits **11***c* and **11***d* and two control circuits **12***c* and **12***d*.

The lighting device according to Embodiment 4 can collectively perform dimming control on two LED units **13***c* and **13***d* by causing a current set circuit **14***c* to output a current command value common to the two control circuits **12***c* and **12***d*.

In Embodiment 4, it is also possible to reduce variations in light output of the two LED units **13***c* and **13***d*.

The luminaire according to Embodiment 4 is particularly suitable when two LED units are provided in a single luminaire for use.

The control circuit in Embodiment 1 is used in the lighting device according to Embodiment 4, but the control circuit in Embodiment 2 may be used.

Moreover, in Embodiment 4, two sets of the step-down chopper circuit, the control circuit, and the LED unit are included. It may also be that three sets or more are included.

Embodiment 5

Next, a lighting device according to Embodiment 5 will be described.

FIG. **13** is a circuit diagram of a lighting device **10***e* according to Embodiment 5. FIG. **14** is a detailed circuit diagram of a control circuit **12***e* included in the lighting device **10***e*. In Embodiment 5, a step-down chopper circuit **11***e* and the control circuit **12***e* are used which have different configurations from those in the above embodiments.

The lighting device **10***e* includes the step-down chopper circuit **11***e*, the control circuit **12***e* that controls the step-down chopper circuit **11***e*, and a dimming control circuit **18***e*. The step-down chopper circuit **11***e* receives a current from a smoothing capacitor C**3** serving as a DC power source, and supplies a predetermined current to an LED unit **13**. In other words, the lighting device **10***e* includes the step-down chopper circuit **11***e*, the control circuit **12***e* for the step-down chopper circuit **11***e*, and the dimming control circuit **18***e*. The step-down chopper circuit **11***e* steps down a DC voltage of the smoothing capacitor C**3** and supplies a DC current to a solid-state light-emitting element (here, the LED unit **13**) serving as a load.

In Embodiment 5, the smoothing capacitor C**3** is included as a DC power source. The smoothing capacitor C**3** is, for example, charged with a DC voltage obtained by full-wave rectifying a commercial AC power source with a full-wave rectifier (not illustrated). In general, an AC input side of the full-wave rectifier is provided with a filter circuit for removing a high frequency component. Further, a power factor improvement circuit using a boosting chopper circuit or the like may be provided between a DC output side of the full-wave rectifier and the smoothing capacitor C**3**.

Moreover, in Embodiment 5, the dimming control circuit **18***e* includes the functions of the current set circuit in each of the above embodiments. The dimming control circuit **18***e* transmits a current command value Iref_i to the control circuit **12***e* (more precisely, to a current comparison circuit **6** in the control circuit **12***e*). Accordingly, the dimming control circuit **18***e*, for example, receives an external dimming signal (not illustrated), sets a target of an output current Iout of the lighting device **10***e* that can achieve a desired light output, and calculates the current command value Iref_i for achieving the output current Iout. The current command value Iref_i is, for example, a voltage corresponding to the magnitude of the output current to be commanded.

The step-down chopper circuit **11***e* includes a switching element Q**2**, an inductor L**2** and a diode D**2** as major structural components. The inductor L**2** is connected in series with the switching element Q**2** and the LED unit **13** that is lit up with a DC current. A current from the smoothing capacitor C**3** flows through the inductor L**2** when the switching element Q**2** is ON. The switching element Q**2** is an element for connecting a series circuit including the inductor L**2** and the LED unit **13** across the smoothing capacitor C**3** serving as a DC power source, and is, for example, a transistor. The diode D**2** is a regenerative diode that supplies, to the LED unit **13**, a current released from the inductor L**2**. In other words, the diode D**2** is connected in parallel with the series circuit including the inductor L**2** and the LED unit **13**, and releases a stored energy of the inductor L**2** to the LED unit **13** when the switching element Q**2** is OFF. Further, an output capacitor C**2** is connected in parallel with the LED unit **13**. The output capacitor C**2** has a capacity set so as to smooth a pulsating component generated due to ON/OFF of the switching element Q**2**, thus allowing a smoothed DC current to flow through the LED unit **13**. The LED unit **13** may be a single LED chip or an LED module obtained by connecting a plurality of LEDs in series, in parallel or in series-parallel.

Resistors R**12** and R**13** illustrated in FIG. **13** are voltage dividing resistors for detecting a voltage Vout_K at a connection point of the LED unit **13** and the inductor L**2**, and belong to a voltage detection circuit **15***e* as described later. The voltage Vout_K is also a voltage at a cathode of the LED unit **13** and thus also referred to as a cathode voltage Vout_K. In a similar manner, resistors R**10** and R**11** are voltage dividing resistors for detecting a voltage Vc3 across the smoothing capacitor C**3**, and belong to the current detection circuit **15***e* as described later. The resistor R**2** is a resistor that constitutes a current detection circuit for detecting a current flowing through the switching element Q**2**.

The control circuit **12***e* generates a signal that turns the switching element Q**2** ON and OFF at high frequencies, and controls a current IL**2** flowing through the inductor L**2** so that an appropriate current flows through the load (LED unit **13**). The control circuit **12***e* includes the current comparison circuit **6**, a ZCD detection circuit **7**, the voltage detection circuit **15***e*, a correction circuit **16***e*, and a drive circuit **17***e*.

FIG. **14** illustrates a simplified internal configuration of the control circuit **12***e* used in Embodiment 5.

The current comparison circuit **6** monitors a voltage at a connection point of the resistor R**2** for current detection and the switching element Q**2**, thereby detecting a current flowing through the switching element Q**2** as a detected value Isense. More specifically, as illustrated in FIG. **14**, the current comparison circuit **6** includes a comparator **60**, a resistor **61** and a capacitor **62**. In the current comparison circuit **6**, a signal indicating the detected value Isense is smoothed by a low pass filter composed of the resistor **61** and the capacitor **62**, and inputted to the comparator **60**. Then, the comparator **60** compares the detected value Isense and a current command value Iref_o from the correction circuit **16***e*, and outputs a signal indicating when the detected value Isense is greater than the current command value Iref_o to the drive circuit **17***e*.

The ZCD detection circuit **7** is an example of a circuit for detecting a time when the inductor L**2** releases a predetermined energy. In Embodiment 5, the ZCD detection circuit **7** detects that a voltage of a secondary winding n**2** coupled to the inductor L**2** is less than or equal to a threshold voltage Vref, thereby detecting that the current IL**2** reaches substantially zero. More specifically, as illustrated in FIG. **14**, the ZCD detection circuit **7** includes a comparator **70**, a reference voltage generator **71** for generating the threshold voltage Vref, and so on. The ZCD detection circuit **7** compares, by the comparator **70**, the voltage of the secondary winding n**2** coupled to the inductor L**2** and the threshold voltage Vref generated by the reference voltage generator **71**. Subsequently, the ZCD detection circuit **7** outputs a signal indicating when the voltage of the secondary winding n**2** is less than the threshold voltage Vref to the drive circuit **17***e*.

The voltage detection circuit **15***e* is an example of a circuit for detecting a voltage (forward voltage) across the LED unit **13** or a voltage across the inductor L**2**. In Embodiment 5, the voltage detection circuit **15***e* is a circuit that detects the voltage Vout across the LED unit **13** serving as a load. As FIG. **14** illustrates, the voltage detection circuit **15***e* includes a differential amplifier **80** for detecting the difference between a voltage Vc3 and the cathode output voltage Vout_K. In the voltage detection circuit **15***e*, the differential amplifier **80** subtracts a voltage obtained by dividing the voltage Vout_K of the cathode side **1** of the LED unit **13** with the resistors R**12** and R**13** from a voltage obtained by dividing the voltage Vc3 of the anode side of the LED unit **13** with the resistors R**10** and R**11**. The voltage detection circuit **15***e* then amplifies the obtained value. With this, the differential amplifier **80** calculates the output voltage Vout (Vout=Vc3−Vout_K) to the LED unit **13**, and outputs the calculated output voltage Vout to the correction circuit **16***e*.

The correction circuit **16***e* corrects the current command value Iref_i from the dimming control circuit **18***e* according to the voltage detected by the voltage detection circuit **15***e* (here, output voltage Vout). The correction circuit **16***e* outputs the corrected value as a current command value Iref_o after correction to the current comparison circuit **6**. More specifically, the correction circuit **16***e* corrects the current command value Iref_i such that, in the relationship between a voltage detected by the voltage detection circuit **15***e* (here, output voltage Vout) and the peak value of a current flowing through the inductor L**2**, the current has peaks that are substantially the same in value at at least two different voltages (output voltage Vout). In order to do so, as FIG. **14** illustrates, the correction circuit **16***e* includes a comparator **90**, a reference voltage generator **91** that generates a reference voltage (first threshold value) Vth1, a transistor **92**, and the like. The comparator **90** compares the output voltage Vout from the voltage detection circuit **15***e* and the first threshold value Vth1 from the reference voltage generator **91**. According to the result of the comparison, the transistor **92** is turned ON or OFF. According to the result of the comparison, the current command value Iref_i from the dimming control circuit **18***e* is outputted as the current command value Iref_o after division with the resistors or without division. More specifically, when the output voltage Vout from the voltage detection circuit **15***e* is less than or equal to the first threshold value Vth1, the transistor **92** is turned ON. Subsequently, the current command value Iref_i from the dimming control circuit **18***e* is outputted as the current command value Iref_o that is a value less than the current command value Iref_i.

The drive circuit **17***e* generates a control signal for turning the switching element Q**2** ON and OFF, and outputs the generated control signal to the gate of the switching element Q**2**. This control signal turns OFF the switching element Q**2** when it is detected that the current value detected by the current comparison circuit **6** (detected value Isense) has reached a predetermined current command value (current command value Iref_o). Further, the control signal turns ON the switching element Q**2** when it is detected that the inductor L**2** has released a predetermined energy (in Embodiment 5, when the ZCD detection circuit **7** detects that the current IL**2** reaches substantially zero). In other words, the drive circuit **17***e* is a circuit that receives the results of detection by the current comparison circuit **6** and the ZCD detection circuit **7**, generates a gate signal of the switching element Q**2**, and drives the switching element Q**2**. Since the resistor R**2** is a small resistor for current detection, it does not substantially affect the gate signal.

More specifically, as FIG. **14** illustrates, the drive circuit **17***e* includes a flip-flop **100**, a buffer amplifier **101** and so on. The flip-flop **100** is reset when the current detected by the current comparison circuit **6** (the detected value Isense) reaches the predetermined current command value Iref_o. Then, the flip-flop **100** is set when the inductor L**2** has released the predetermined energy (when the ZCD detection circuit **7** detects that the current IL**2** reaches substantially zero). The buffer amplifier **101** outputs an output signal from the flip-flop **100** to the gate of the switching element Q**2** as a control signal.

Next, a description is given of an operation of the lighting device **10***e* according to Embodiment 5 configured as above.

First, peak current control and Boundary Current Mode (BCM) control, which are basic operations of the step-down chopper circuit **11***e* in Embodiment 5, will be described. They are the same as the operations described in PTL 1. In the peak current control, the switching element Q**2** is turned OFF when the current IL**2** of the inductor L**2** reaches a predetermined value. In the BCM control, the switching element Q2 is turned ON when the current IL2 reaches substantially zero.

When the switching element Q2 is ON, a current flows from a positive electrode of the smoothing capacitor C3 via the output capacitor C2, the inductor L2, the switching element Q2 and the resistor R2 to a negative electrode of the smoothing capacitor C3. At this time, a chopper current i flowing through the inductor L2 increases substantially linearly unless the inductor L2 is magnetically saturated. The voltage across the inductor L2 is a difference between the voltage Vc3 across the smoothing capacitor C3 and a voltage Vc2 across the output capacitor C2. Hence, the current i of the inductor L2 has a substantially constant inclination di/dt (≈(Vc3−Vc2)/L2). Thus, when the voltage Vc2 across the output capacitor C2, namely, the output voltage thereof is high, the current i of the inductor L2 slowly increases. When the output voltage thereof is small, the current i increases rapidly.

The value of a current flowing through the inductor L2 while the switching element Q2 is ON is detected by the current comparison circuit **6** from the voltage generated in the resistor R2 connected in series with the switching element Q2. The current comparison circuit **6** includes, for example, the comparator **60** that compares the detected value Isense and the current command value Iref_o. The current command value Iref_o is a value obtained by correcting the current command value Iref_i from the dimming control circuit **18***e* by the correction circuit **16***e*. The current command value Iref_i is set by the dimming control circuit **18***e* so that a current peak target value Ipeak_T is twice as much as a target value Iout_T of the output current according to a detection ratio of the detected current value Isense detected by the resistor R2 (a ratio between an actual current value and a detected voltage). For example, when R2=0.1Ω and Iout_T=1 A, Ipeak_T=2 A and Iref=0.2 V.

Thus, when an inductor current reaches the current peak target value ipeak_T defined by the current command value Iref, the detected value Isense of the current comparison circuit **6** exceeds the current command value Iref_o, so that an output of the comparator **60** results in a High level. Consequently, a reset signal is inputted to a reset input terminal R of the flip-flop (FF) **100** in the drive circuit **17***e*. This causes a Q output of the flip-flop **100** to be at a Low level. Accordingly, a gate-source electric charge of the switching element Q2 is extracted, so that the switching element Q2 is turned OFF immediately.

While the switching element Q2 is OFF, an electromagnetic energy stored in the inductor L2 is released to the output capacitor C2 via the diode D2. At this time, since the voltage across the inductor L2 is clamped by the voltage Vc2 of the output capacitor C2, a current i of the inductor L2 decreases at a substantially constant inclination di/dt (≈−Vc2/L2).

During a period in which the current i is flowing through the inductor L2, a voltage corresponding to the inclination of the current i of the inductor L2 is generated in the secondary winding n2 of the inductor L2. This voltage disappears when the current i of the inductor L2 finishes flowing. The ZCD detection circuit **7** detects this timing.

The ZCD detection circuit **7** includes the comparator **70** for zero cross detection. The voltage generated in the secondary winding n2 of the inductor L2 is connected to a negative input terminal of the comparator **70**. The reference voltage Vref for zero cross detection generated in the reference voltage generator **71** is applied to a positive input terminal of the comparator **70**. When the voltage of the secondary winding n2 disappears, an output of the comparator **70** turns to a High level, and a set pulse is supplied to a set input terminal S of the flip-flop **100** in the drive circuit **17***e*. Consequently, the Q output of the flip-flop **100** turns to a High level, and a gate signal of the switching element Q2 is applied so as to turn ON the switching element Q2.

By repeating such operations, the inductor current achieves a waveform that has a constant peak value and turns back up at a point of substantially zero. At this time, the output voltage Vout is equal to the voltage Vc2 across the output capacitor C2, and the output current Iout has a value of an average of the inductor current, namely, about a half of the peak current value.

An increase in the output voltage Vout automatically extends an ON time of the switching element Q2 and shortens an OFF time thereof. A decrease in the output voltage Vout automatically shortens the ON time of the switching element Q2 and extends the OFF time thereof. Therefore, it is possible to maintain constant current properties regardless of the voltage characteristics of the load (LED unit **13**).

Now, as mentioned earlier in the background art section, since the components constituting the step-down chopper circuit **11***e* have a delay time, there occurs a delay time td0 from the timing of detecting a current peak before the switching OFF.

As FIG. **15** illustrates, due to such a delay time td0, an actual peak value Ipeak_R of the current IL2 flowing through the inductor L2 is greater than the current peak target value Ipeak_T (current command value). FIG. **15** illustrates variations in actual current peak value Ipeak_R of a current flowing through the inductor L2 (the inductor current IL2) in a lighting device of a background art. A section on the left in FIG. **15** illustrates various exemplary current peak values Ipeak_R, and a section on the right in FIG. **15** illustrates an enlarged view of a waveform of the inductor current IL2 near the current peak value Ipeak_R. As can be understood from the formula below, with a decrease in the output voltage Vout of the step-down chopper circuit **11***e*, the difference between the actual peak current value Ipeak_R and the current peak target value Ipeak_T: Δipeak=Ipeak_R−Ipeak_T increases.

$$\Delta ipeak = Ipeak\_R - Ipeak\_T = di/dt \times td0 = (Vc3 - Vout)/L \times td0$$

This is because, even if the delay time td0 is constant, the inclination of the current of the inductor L2 during the period where the switching element Q2 is ON is di/dt≈(Vc3−Vout)/L2, i.e., and the inclination di/dt varies depending on the output voltage Vout. Accordingly, when the step-down chopper circuit **11***e* is operated merely by the BCM control and the peak current control, the output voltage-current characteristics do not achieve perfect constant current characteristics but achieve characteristics as in a background art illustrated in FIG. **16** in which the output current increases with a decrease in the output voltage Vout. FIG. **16** illustrates the output voltage-current characteristics in a lighting device of a background art. The output voltage-current characteristics illustrated here are as follows.

$$Iout = Ipeak\_R/2 = (\Delta ipeak + Ipeak\_T)/2 = (Vc3 - Vout)/L \times td0/2 + Ipeak\_T/2$$

In an actual lighting device having such characteristics, when there is an individual difference in forward voltage (namely, output voltage Vout) among loads (LED unit **13**) to be connected, the output current varies individually, resulting in variations in light output. Also, when different types of loads having the same current rating and different voltage ratings are connected or when a plurality of the same loads are connected in series in a circuit, it might not be able to achieve desired light output because the difference in output voltage causes the output current to deviate from a rated range.

For example, when a plurality of LED modules with a forward voltage (namely, a voltage Vout) rated at 100 V are connected in series to a lighting device having the output characteristics shown in FIG. **16**, the output current is 1.10 A in the case where the number of the series-connected loads is one (Vout=100 V), and the output current is 1.07 A in the case where the number thereof is two (Vout=200 V). The output current varies by 30 mA. Accordingly, even when the same LED modules are used, the light output per LED module varies depending on the number of the LED modules connected in series. Incidentally, the condition for calculating the above-noted output current is Vc3=420 V, inductor L=800 uH, td0=500 nS and Ipeak_T=2 A.

Thus, in Embodiment 5, the correction circuit **16***e* is included in the control circuit **12***e*. The correction circuit **16***e* corrects the current command value Iref_i provided from the dimming control circuit **18***e*, when the output voltage Vout detected by the voltage detection circuit **15***e* is less than or equal to the first threshold value. In this way, the difference Δipeak between the actual peak current value Ipeak_R of the inductor current IL**2** and the current peak target value Ipeak_T is kept constant regardless of the output voltage Vout. In Embodiment 5, it is controlled such that, in the relationship between the output voltage Vout detected by the voltage detection circuit **15***e* and the peak value of a current flowing through the inductor L**2**, the current value has peaks that are substantially the same in value at at least two different output voltages Vout.

The correction circuit **16***e* receives the current command value Iref_i from the dimming control circuit **18***e* as input, and outputs the current command value Iref_o as output. More specifically, when the output voltage Vout detected by the voltage detection circuit **15***e* is greater than the first threshold value Vth1, the correction circuit **16***e* outputs the current command value Iref_i from the dimming control circuit **18***e* without change as the current command value Iref_o. On the other hand, when the output voltage Vout is less than or equal to the first threshold value Vth1, the correction circuit **16***e* attenuates (divides voltage of) the current command value Iref_i from the dimming control circuit **18***e*. The correction circuit **16***e* then outputs the current command value Iref_o where Iref_o<Iref_i.

With such an operation, a difference is reduced which is caused due to the output voltage Vout of the actual peak current value Ipeak_R.

FIG. **17** illustrates the relationship between the output voltage Vout and the current command value Iref (Iref_i, Iref_o) when Vc3=420 V, Td0=500 nS, inductor L=800 uH, and Ipeak_T=2 A. The current command value Iref_o outputted from the correction circuit **16***e* is obtained by correcting the current command value Iref_i=0.2 in a step like manner such that Iref_o=0.194 where Vout<150 V,

With such a correction of the current command value, as FIG. **18** illustrates, the difference in actual peak current value Ipeak_R due to the output voltage Vout can be reduced. FIG. **18** illustrates the output voltage-current characteristics in the lighting device **10***e* according to Embodiment 5. As seen from the comparison between FIG. **16** in the background art and FIG. **18**, the lighting device **10***e* according to Embodiment 5 have the output voltage-current characteristics which have small variations caused due to the voltage Vout.

When LED modules with a forward voltage Vout rated at 100 V are connected to the lighting device having the output voltage-current characteristics illustrated in FIG. **18**, the output current is 1.070 A in the case where the number of the series-connected loads is one (Vout=100 V). The output current is 1.070 A also in the case where the number thereof is two (Vout=200 V). In this way, the output current does not vary. The condition for calculating the above-noted output current is Vc3=420 V, inductor L=800 uH, Td0=500 nS, and Ipeak_T=2 A.

In such a way, according to Embodiment 5, the output current can be kept substantially the same even (output voltage dependency of the output current is reduced) when the number of the series connected LEDs as the LED unit **13** is changed, by correcting the current command value Iref_i from the dimming control circuit **18***e*.

In order to obtain effective functions of the correction circuit **16***e* according to Embodiment 5, it is set such that the first threshold value Vth1 falls between the forward voltages Vr1 and Vr2 of the two LED units **13** having different forward voltages among the LED units **13** to be connected to the lighting device **10***e*. For example, Vth1 is set such that a relation of Vr1<Vth1<Vr2 is satisfied. The output current rapidly changes near the output voltage at which the comparator **90** in the correction circuit **16***e* is switched. Hence, it may be that the first threshold value Vth1 is set to the output voltage that is not normally adopted. For example, the first threshold value Vth1 may be set to an intermediate value of the output voltage of the loads (LED units **13**) to be connected. In the above calculation example, the output voltage is assumed to be 100 V or 200 V. Hence, 150V that is the intermediate value is selected as the first threshold value Vth1. The first threshold value Vth1 may have a predetermined hysteresis value.

The step-down chopper circuit **11***e* that can achieve the present embodiment does not have to be the circuit illustrated in FIG. **13** but may be a converter in which the inclination of a current flowing through the inductor varies according to the output voltage when the switching element Q**2** is ON. In other words, the step-down chopper circuit according to Embodiment 5 is appropriate as long as it is of a type in which a current flows from the positive electrode of the smoothing capacitor C**3** via the output capacitor C**2** and the inductor L**2** to the negative electrode of the smoothing capacitor C**3**. It should be noted that details, for example, a positive and a negative of the logic in the detection circuits sometimes have to be changed partially according to the circuit configuration to be adopted.

As described above, in Embodiment 5, when the output voltage detected by the voltage detection circuit **15***e* is less than or equal to the first threshold value, the correction circuit **16***e* corrects the current command value Iref_i from the dimming control circuit **18***e*. This makes it possible to achieve the lighting device **10***e* that keeps the output current Iout constant regardless of the output voltage Vout (the lighting device **10***e* in which the dependency of the output current Iout on the output voltage Vout is reduced). Thus, even when loads (LED units **13**) with different voltage ratings are connected or when the number of series-connected LEDs as loads is changed, a desired light output can be obtained.

Embodiment 6

Next, a lighting device according to Embodiment 6 of the present invention will be described.

The lighting device according to Embodiment 6 is different from that in Embodiment 5 in that the correction circuit changes the relationship between the output voltage Vout and the current command value Iref_o at plural switching points (that is, threshold values). Hereinafter, the following description of Embodiment 6 will be directed only to the differences (correction circuit) from Embodiment 5.

FIG. 19 is a detailed circuit diagram of a correction circuit 16f according to Embodiment 5. As FIG. 19 illustrates, the correction circuit 16f includes: two comparators 190 and 192, two reference voltage generators 191 and 193; two transistors 194 and 195, and resistors 196 to 198; and the like. The correction circuit 16f corresponds to two sets of the correction circuit 16e according to Embodiment 5 (with different reference voltages). The reference voltages generated by the two reference voltage generators 191 and 193 (a first threshold value Vth1 and a second threshold value Vth2) are set so as to satisfy Vth2<Vth1.

In the correction circuit 16f having such a configuration, the output voltage Vout from the voltage detection circuit 15e is compared by the comparators 190 and 192 with the second threshold value Vth2 and the first threshold value Vth1. The transistors 194 and 195 are turned ON and OFF according to the comparison results. The current command value Iref_i is divided according to a first division ratio or a second division ratio, or output as the current command value Iref_o without being divided.

More specifically, when the output voltage Vout from the voltage detection circuit 15e is greater than the first threshold value Vth1 (Vth1<Vout), the comparators 192 and 190 output Low level signals, and the two transistors 194 and 195 are turned OFF. As a result, the current command value Iref_i from the dimming control circuit 18e is outputted as the current command value Iref_o without being divided.

When the output voltage Vout from the voltage detection circuit 15e is greater than the second threshold value Vth2 and less than or equal to the first threshold value Vth1 (Vth2<Vout Vth1), the comparator 192 outputs a High level signal and the comparator 190 outputs a Low level signal. As a result, only the transistor 194 is turned ON out of the two transistors 194 and 195. The current command value Iref_i from the dimming control circuit 18e is divided according to the first division ratio determined by the resistors 196 and 197, and is outputted as the current command value Iref_o.

When the output voltage Vout from the voltage detection circuit 15e is less than or equal to the second threshold value Vth2 (Vout Vth2), the comparators 192 and 190 outputs high level signals, and the two transistors 194 and 195 are turned ON. As a result, the current command value Iref_i from the dimming control circuit 18e is divided according to the second division ratio (<first division ratio) determined by the resistor 196 and combined parallel resistance of the resistors 197, and 198. The obtained value is outputted as the current command value Iref_o.

With such an operation, the correction circuit 16f can change the current command value Iref_o at two points of Vout (the first threshold value Vth1 and the second threshold Vth2) as illustrated in FIG. 20. This results in the output voltage-current characteristics as illustrated in FIG. 21. FIG. 20 illustrates an example of the relationship between the output voltage Vout and the current command value Iref (Iref_i and Iref_o) of the lighting device according to Embodiment 6. FIG. 21 illustrates the output voltage-current characteristics in the lighting device according to Embodiment 6.

As seen from the comparison between FIG. 16 in the background art and FIG. 21, the lighting device according to Embodiment 6 can further reduce the difference in the actual peak current value Ipeak_R due to the output voltage Vout. By making the correction circuit 16f have plural voltage switching points in such a manner, a larger number of loads (the LED units 13) having different rated voltages can be connected to the lighting device (in other words, the lighting device can supply substantially constant output current).

For example, it is possible to output substantially the same current to the LED unit 13 when Vout=100 V, 200 V, and 300 V with the characteristics illustrated in FIG. 21.

In order to obtain effective functions of the correction circuit 16f according to Embodiment 6, it is set such that the first threshold value Vth1 and the second threshold value Vth2 fall between the forward voltages Vr1 and Vr2 of two LED units 13 having different forward voltages among the LED units 13 to be connected to the lighting device. For example, the values are preferably set to satisfy Vr1<Vth2<Vth1<Vr2.

Embodiment 7

Next, a lighting device according to Embodiment 7 of the present invention will be described.

The lighting device according to Embodiment 7 is different from that in Embodiment 5 in that a correction circuit detects a cathode voltage Vout_K that varies according to an output voltage Vout, and continuously corrects the current command value Iref according to the cathode voltage Vout_k. With this, it is possible to achieve a lighting device that reliably keeps the output current Iout constant regardless of the output voltage Vout. Hence, the lighting device according to Embodiment 7 is obtained by partially changing the voltage detection circuit 15e and the correction circuit 16e in the lighting device 10e according to Embodiment 5. Hereinafter, the following description of Embodiment 7 will be directed only to the differences (the voltage detection circuit and the correction circuit) from Embodiment 5.

FIG. 22 is a detailed circuit diagram of a voltage detection circuit 15g and a correction circuit 16g according to Embodiment 7.

The voltage detection circuit 15g divides the cathode voltage Vout_K with the resistors R12 and R13, and outputs the obtained divided voltage to the correction circuit 16g. During the period in which the switching element Q2 is ON, the cathode voltage Vout_K is substantially equal to the voltage VL across the inductor L2. This is because the ON resistance of the switching element Q2 and the resistor R2 are so small as to be negligible. In Embodiment 7, the voltage detection circuit 15g detects the cathode voltage Vout_K, thereby detecting the voltage VL across the inductor L2 during the period in which the switching element Q2 is ON.

The correction circuit 16g corrects the current command value Iref_i such that the peak value of a current flowing through the inductor L2 is kept constant regardless of the magnitude of the voltage detected by the voltage detection circuit 15g. More specifically, the correction circuit 16g continuously corrects the current command value Iref according to the voltage detected by the voltage detection circuit 15g (here, the cathode voltage Vout_K). For that purpose, the correction circuit 16g includes a transconductance amplifier 290, a reference voltage generator 291 that generates a reference voltage (a threshold voltage Vth), a transistor 292, and the like.

The voltage detection circuit 15g and the correction circuit 16g configured as above operate as below.

The voltage detection circuit 15g outputs the voltage obtained by dividing the cathode voltage Vout_K to the correction circuit 16g.

In the correction circuit 16g, the transconductance amplifier 290 outputs, to the base of the transistor 292, a current corresponding to a difference between the voltage from the voltage detection circuit 15g and the threshold voltage Vth generated by the reference voltage generator 291. The current command value Iref_o after correction is equal to a value obtained by dividing the input current command value Iref_i according to the resistors illustrated and a collector current of the transistor **292** (in other words, on-resistance of the transistor **292**).

With the voltage detection circuit **15***g* and the correction circuit **16***g*, the collector current of the transistor **292** increases with an increase in the cathode voltage Vout_K, so that the current command value Iref_o after correction continuously decreases. In other words, according to the above described relationship between the output voltage Vout and the cathode voltage Vout_K (Vout=Vc3−Vout_K), the generated current command value Ifref_o decreases as the output voltage Vout decreases.

The threshold voltage Vth generated by the reference voltage generator **291** is set as an offset value which appropriately relates the cathode voltage Vout_K (or the output voltage Vout) and the current command value Iref_o after correction.

The experimental results obtained by the voltage detection circuit **15***g* and the correction circuit **16***g* are shown in FIG. **23** (current command value correction) and FIG. **24** (voltage-current characteristics). In other words, FIG. **23** illustrates an example of the relationship between the output voltage Vout and the current command value Iref_o after correction of the lighting device according to Embodiment 7. FIG. **24** illustrates the output voltage-current characteristics in the lighting device according to Embodiment 7.

As FIG. **23** illustrates, in Embodiment 7, the current command value Iref_o after correction continuously varies in such a manner that the current command value Iref_o after correction increases as the output voltage Vout of the lighting device increases. Moreover, as seen from the comparison between FIG. **24** and the lighting device of a background art in FIG. **16**, the output current Iout is constant regardless of the output voltage Vout.

In this manner, according to the lighting device in Embodiment 7, the current command value Iref_i from the dimming control circuit **18***e* is corrected such that the current flowing through the inductor L**2** has a constant peak value regardless of the voltage detected by the voltage detection circuit **15***g*. As a result, constant output current Iout is ensured regardless of the output voltage Vout.

Embodiment 8

Next, a lighting device according to Embodiment 8 of the present invention will be described.

Embodiment 8 is different from Embodiments 5 to 7 in that plural step-down chopper circuits, control circuits, solid-state light-emitting elements (here, LED units) are included.

FIG. **25** is a circuit diagram of a lighting device according to Embodiment 8.

Here, for example, a description is given using a circuit of a lighting device including three step-down chopper circuits **11***h* to **11***j*. The lighting device includes step-down chopper circuits **11***h* to **11***j* for stepping down a DC voltage of the smoothing capacitor C**3** serving as a common DC power source and supplying a DC current to LED units **13***h* to **13***j* serving as loads, and control circuits **12***h* to **12***j*.

Each of the step-down chopper circuits **11***h* to **11***j* has a circuit configuration similar to that of the step-down chopper circuit **11***e* in Embodiment 5. For example, the step-down chopper circuit **11***h* includes an inductor L**2***h*, a switching element Q**2***h*, a diode D**2***h* and an output capacitor C**2***h*.

Each of the control circuits **12***h* to **12***j* has a circuit configuration similar to the control circuit **12***e* in Embodiment 5. For example, the control circuit **12***h* includes a current comparison circuit **6***h*, a ZCD detection circuit **7***h*, a voltage detection circuit **15***h*, a correction circuit **16***h* and a drive circuit **17***h*. A common current command value Iref_i is inputted from a dimming control circuit **18***e* to the three control circuits **12***h* to **12***j*.

Each of the step-down chopper circuits **11***h* to **11***j* and its corresponding one of the control circuits **12***h* to **12***j* operate independently of each other and similarly to Embodiment 5. For example, as for the step-down chopper circuit **11***h* and the control circuit **12***h*, when the output voltage detected by the voltage detection circuit **15***h* is less than or equal to the first threshold value, the correction circuit **16***h* corrects the current command value Iref_i. In this way, the peak value of a current flowing through the inductor L2 is kept constant regardless of the output voltage (or the variation range is reduced). As a result, it is possible to achieve a lighting device that keeps an output current constant regardless of the output voltage (or the variation range of the output current is reduced).

FIG. **26** illustrates exemplary waveforms of currents IL_h to IL_j flowing through the inductors in the respective step-down chopper circuit **11***h* to **11***j*. The correction circuit included in each of the control circuits **12***h* to **12***j* is similar to the correction circuit **16***f* in Embodiment 6. The three step-down chopper circuits **11***h* to **11***j* are connected with the following loads (LED units **13***h* to **13***j*) having different rated voltages. In other words, the LED unit **13***h* connected to the step-down chopper circuit **11***h* has a rated voltage Vout_h=100 V, the LED unit **13***i* connected to the step-down chopper circuit **11***i* has a rated voltage Vout_i=200 V, and the LED unit **13***j* connected to the step-down chopper circuit **11***j* has a rated voltage Vout_j=300 V.

As becomes clear from the exemplary waveforms in FIG. **26**, although ON times Ton of the switching elements and current inclinations Δi are different among the step-down chopper circuits **11***h* to **11***j*, the target value Iref_i is corrected according to the output voltage Vout. With this, the current peak value Ipeak_R is kept substantially constant, so that the output current can be kept substantially constant.

In this way, according to Embodiment 8, it is possible to obtain a lighting device that has a constant output current regardless of the output voltage, by ensuring constant current properties of the output voltage-current characteristics at each output. Furthermore, even when LEDs with different rated voltages are connected to respective outputs, or when the number of LEDs connected in series is changed, a desired current can be passed, thereby obtaining a desired light output.

As described above, in Embodiment 8, it is possible to achieve a lighting device capable of ensuring a desired light output in each output and reducing the variations in light output among the entire light outputs.

It should be noted that, although the lighting device in Embodiment 8 includes three sets of the step-down chopper circuit and the control circuit of Embodiment 5, the lighting device may include less or greater number of sets of the step-down chopper circuit and the control circuit or may include the step-down chopper circuit and the control circuit of Embodiment 6 or 7.

Embodiment 9

Next, a luminaire according to Embodiment 9 of the present invention will be described.

FIGS. **27** to **29** illustrate external appearances of luminaires **200***k* to **200***m* according to Embodiment 9.

FIG. **27** illustrates an example where the luminaire **200***k* is applied to a recessed light. FIG. **28** and FIG. **29** illustrate examples where the luminaires **200***l* and **200***m* are applied to spot lights.

The luminaires **200***k* to **200***m* illustrated in FIG. **27** to FIG. **29** respectively include circuit boxes **201***k* to **201***m* and lamps **202***k* to **202***m*. The luminaire **200***k* illustrated in FIG. **27** and the luminaire **200***m* illustrated in FIG. **29** further include wiring **203***k* and **203***m*, respectively.

Each of the circuit boxes **201***k* to **201***m* includes one of the lighting devices according to the above described embodiments. Each of the lamps **202***k* to **202***m* is provided thereon with an LED unit.

The wiring **203***k* is wiring for electrically connecting the circuit box **201***k* and the lamp **202***k*. The wiring **203***m* is wiring for electrically connecting the circuit box **201***m* and the lamp **202***m*.

In Embodiment 9, the above described lighting devices are used for the luminaires **200***k* to **200***m*, so that a current flowing through the LED unit has a desired current value. Hence, it is possible to reduce variations in light output of each luminaire when the luminaires **200***k* to **200***m* are installed in the same space.

Moreover, when each of the luminaires **200***k* to **200***m* includes a plurality of LED units, it is possible to reduce color unevenness among the LED units.

As described above, the lighting device according to the above described embodiments is a lighting device that is connected to a DC power source to supply a current to a solid-state light-emitting element. The lighting device includes: a DC/DC converter; and a control circuit. The DC/DC converter includes: a switching element that is connected to the DC power source and is turned ON and OFF; an inductor that is connected in series with the switching element, and through which the current from the DC power source flows when the switching element is ON; a diode that supplies, to the solid-state light-emitting element, the current released from the inductor; and a current detection circuit that detects a current flowing through the switching element and outputs a detected current value that is a value of the current detected. The control circuit includes: a drive circuit that turns the switching element ON and OFF; a voltage detection circuit that detects either one of a voltage across the solid-state light-emitting element and a voltage across the inductor, and outputs a detected voltage value that is a value of the voltage detected; and a correction circuit that corrects a timing at which the drive circuit turns OFF the switching element. When the drive circuit detects that the inductor has finished releasing energy, the drive circuit turns ON the switching element, and when the detected current value reaches a predetermined current command value, the drive circuit turns OFF the switching element, and the correction circuit corrects the timing at which the drive circuit turns OFF the switching element, based on the detected voltage value.

In this manner, the variations in output current that depends on the magnitude of the output voltage of the lighting device is reduced. Thus, even when there are variations in forward voltage or rated voltage among the solid-state light-emitting elements, a current defined by the current command value and having a value within a predetermined range is outputted to the solid-state light-emitting elements. Further, such a lighting device is realized by a relatively simple configuration. Accordingly, it is possible to achieve a lighting device which includes a switching power source circuit and which can stably light up solid-state light-emitting elements having different properties while reducing variations in light output of these elements with a simple configuration.

Moreover, in Embodiment 1, the correction circuit corrects the current command value based on the detected voltage value, so that the timing at which the drive circuit turns OFF the switching element is corrected.

With this, a constant current can be outputted to the solid-state light-emitting elements simply by adding a simple circuit to a portion of the control circuit that receives a signal from the current set circuit.

Moreover, in Embodiment 1, the correction circuit further corrects the current command value such that the corrected current command value has a positive correlation with the detected voltage value.

This allows more accurate control of the current output to the solid-state light-emitting elements.

Moreover, in Embodiment 2, the correction circuit corrects the current command value based on the detected voltage value, so that the timing at which the drive circuit turns OFF the switching element is corrected.

With this, a constant current can be outputted to the solid-state light-emitting elements simply by adding a simple circuit to a portion of the control circuit that receives a signal from the current set circuit.

Moreover, in Embodiment 2, the correction circuit corrects the current command value such that the corrected current command value has a negative correlation with the detected voltage value.

This allows more accurate control of the current output to the solid-state light-emitting elements.

Moreover, in Embodiment 3, a dimming control circuit which varies the current command value is further included.

With this, the solid-state light-emitting elements can be dimmed and lit up with a desired light output.

Moreover, in Embodiment 4, a plurality sets each including the DC/DC convertor and the control circuit are included.

With this, a same current defined by a common target current value is outputted to a plurality of solid-state light-emitting elements. Hence, it is possible to reduce variations in light output from respective solid-state light-emitting elements.

Furthermore, in Embodiment 5, the correction circuit **16***e* and the like correct a current command value such that, in the relationship between the voltage detected by the voltage detection circuit **15***e* or the like and the peak value of the current flowing through the inductor L**2**, the current value has peaks that are substantially the same in value at at least two different voltages.

In this manner, the variations in the output current that depends on the magnitude of the output voltage is reduced. Thus, even when there are variations in forward voltage or rated voltage among the solid-state light-emitting elements, a current defined by the current command value and having a value within a predetermined range is outputted to the solid-state light-emitting elements. Further, such constant current control is realized by a simple correction circuit. Accordingly, it is possible to achieve a lighting device which includes a switching power source circuit that is operated by the BCM control and the peak current control and which can stably light up solid-state light-emitting elements having different properties while reducing variations in light output of these elements with a simple configuration.

Moreover, in Embodiment 5, the correction circuit **16***e* corrects the current command value to a first correction value that is less than the current command value, when the output voltage detected by the voltage detection circuit **15***e* is less than or equal to the first threshold value. Accordingly, when the output voltage detected by the voltage detection circuit is less than or equal to the first threshold value, the current command value is corrected to the first correction value that is less than the current command value, thereby reducing variations in peak value of the current flowing through the inductor.

Moreover, in Embodiment 6, the correction circuit **16***f* further corrects the current command value to a second correction value that is less than the first correction value, when the output voltage detected by the voltage detection circuit **15***e* is less than or equal to the second threshold value that is less than the first threshold value. With this, a plurality of switching points (that is, threshold values) at which the relationship between the output value and the current command value is switched are provided, thereby further reducing variations in peak value of the current flowing through the inductor.

As for the thresholds, the first threshold value and the second threshold value fall between the values of the different forward voltages of two solid-state light-emitting elements among the solid-state light-emitting elements to be connected to the lighting device. Accordingly, the threshold values are set to be within a range of the forward voltages of the solid-state light-emitting elements to be connected to the lighting device. Hence, it is possible to reliably reduce variations in peak value of the current flowing through the inductor.

Moreover, in Embodiment 7, the correction circuit **16***g* corrects the current command value such that the peak value of the current flowing through the inductor L**2** is constant regardless of the voltage detected by the voltage detection circuit **15***g*. Accordingly, the peak value of the current flowing through the inductor becomes constant regardless of the voltage detected by the voltage detection circuit **28**. Hence, the output current is kept constant regardless of the output voltage.

Furthermore, in Embodiment 8, the lighting device is a device that lights up a plurality of solid-state light-emitting elements. The lighting device includes: the step-down chopper circuits **11***h* to **11***j* corresponding to a different one of the solid-state light-emitting elements; and the control circuits **12***h* to **12***j* that respectively control the step-down chopper circuits **11***h* to **11***j*. The lighting device further includes the dimming control circuit **18***e* that outputs a current command value determined according to a desired light output to the control circuits **12***h* to **12***j*. In this way, since the same output current defined by a common current command value is applied to the solid-state light-emitting elements, the magnitude of the light output evens out among the solid-state light-emitting elements. As a result, illumination is performed with reduced light output variations as a whole.

Furthermore, in Embodiment 9, the luminaire includes the lighting device according to one of the above described embodiments and one or more solid-state light-emitting elements.

Hence, it is possible to reduce variations in light output of each luminaire when a plurality of luminaires are installed in the same space. Moreover, when a luminaire includes a plurality of solid-state light-emitting elements, it is possible to reduce color unevenness among the solid-state light-emitting elements.

The above description has been directed to the lighting device and the luminaire according to the present invention, with reference to the embodiments. However, the present invention is not limited to these embodiments. As long as not departing from the purpose of the present invention, various modifications that are conceived by a person with ordinary skill in the art and made to the present embodiments and modes that are constructed by combining the structural components in different embodiments may also fall within one or more aspects of the present invention.

For example, although the lighting device in the above-described embodiments has used the LED element as the solid-state light-emitting element, the solid-state light-emitting element in the present invention may be any other solid-state light-emitting element such as an organic EL element.

Moreover, when the lighting devices in the above-described embodiments are applied to a plurality of luminaires, one type of the lighting devices in Embodiments 1 to 8 above may be applied to all the luminaires or plural types of the above-noted lighting devices may be mixed and applied to the plurality of luminaires. Further, when the lighting device in Embodiments 4 and 8 above is applied to a plurality of luminaires, plural sets of the step-down chopper circuit and the control circuit may be divided and received in individual luminaires or may be put together and received in a single luminaire.

Furthermore, in the lighting device according to the above embodiments, the step-down chopper circuit is used as an example of the DC/DC converter. The DC/DC converter according to the present invention, however, is not limited to the step-down chopper circuit in the above embodiments. The DC/DC converter may be any DC/DC converters as long as they have a switching element, an inductor, and a diode, and operates as described below. More specifically, any DC/DC convertors can be used in which a current flows through the inductor and energy is stored when the switching element is ON, and the energy stored in the inductor is discharged through the diode when the switching element is OFF.

While the foregoing has described what are considered to be the best mode and/or other examples, it is understood that various modifications may be made therein and that the subject matter disclosed herein may be implemented in various forms and examples, and that they may be applied in numerous applications, only some of which have been described herein. It is intended by the following claims to claim any and all modifications and variations that fall within the true scope of the present teachings.

The invention claimed is:

1. A lighting device that is connected to a DC power source to supply a current to a solid-state light-emitting element, the lighting device comprising:

a DC/DC converter; and

a control circuit,

wherein the DC/DC converter includes:

a switching element that is connected to the DC power source and is turned ON and OFF;

an inductor that is connected in series with the switching element, and through which the current from the DC power source flows when the switching element is ON;

a diode that supplies, to the solid-state light-emitting element, the current released from the inductor; and

a current detection circuit that detects a current flowing through the switching element and outputs a detected current value that is a value of the current detected,

the control circuit includes:

a drive circuit that turns the switching element ON and OFF;

a voltage detection circuit that detects either one of a voltage across the solid-state light-emitting element and a voltage across the inductor, and outputs a detected voltage value that is a value of the voltage detected; and

a correction circuit that corrects a timing at which the drive circuit turns OFF the switching element,

when the drive circuit detects that the inductor has finished releasing energy, the drive circuit turns ON the switching element, and when the detected current value reaches a predetermined current command value, the drive circuit turns OFF the switching element, and the correction circuit corrects the timing at which the drive circuit turns OFF the switching element, based on the detected voltage value.

2. The lighting device according to claim **1**,

wherein the correction circuit corrects the timing at which the drive circuit turns OFF the switching element, by correcting the predetermined current command value based on the detected voltage value.

3. The lighting device according to claim **2**,

wherein the correction circuit corrects the predetermined current command value such that, in a relationship between the detected voltage value and a peak value of the detected current value, the detected current value has peaks that are substantially the same in value at two or more different detected voltage values among a plurality of the detected voltage values.

4. The lighting device according to claim **2**,

wherein when the detected voltage value is less than or equal to a first threshold value, the correction circuit corrects the predetermined current command value to a first correction value that is less than the predetermined current command value.

5. The lighting device according to claim **4**,

wherein when the detected voltage value is less than or equal to a second threshold value that is less than the first threshold value, the correction circuit further corrects the predetermined current command value to a second correction value that is less than the first correction value.

6. The lighting device according to claim **5**,

wherein the first threshold value and the second threshold value fall between values of different forward voltages of two solid-state light-emitting elements among a plurality of the solid-state light-emitting elements to be connected to the lighting device.

7. The lighting device according to claim **4**,

wherein the correction circuit corrects the detected current value such that the detected current value after correction has a negative correlation with the detected voltage value.

8. The lighting device according to claim **2**,

wherein the correction circuit corrects the predetermined current command value such that a peak value of the current flowing through the inductor is constant regardless of the voltage detected by the voltage detection circuit.

9. The lighting device according to claim **2**,

wherein the correction circuit corrects the predetermined current command value such that the predetermined current command value after correction has a positive correlation with the detected voltage value.

10. The lighting device according to claim **1**,

wherein the correction circuit corrects the timing at which the drive circuit turns OFF the switching element, by correcting the detected current value based on the detected voltage value.

11. The lighting device according to claim **1**, comprising

a plurality of sets each including the DC/DC converter and the control circuit.

12. The lighting device according to claim **1**, further comprising

a dimming control circuit that changes the predetermined current command value.

13. A luminaire comprising:

the lighting device according to claim **1**; and

a solid-state light-emitting element.

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